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99626

FINAL TECHNICAL REPORT

S-047 EXPERIMENT

CEI NAS 9-7457-V.A.

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I. Background

A. Introduction

Improvements in man's understanding of atmospheric processes and in his ability to forecast weather parameters through longer periods are known to be quite dependent upon data coverage. The initial conditions for numerical weather prediction models are still, to a surprising extent, composed of an initial guess field updated by observations. However, such observations are not forthcoming over much of the Earth's oceanic surfaces, with the exception of satellite visual and infra-red photography. Thus the useful quantitative parameters for weather forecasting or research on a hemispheric scale are in good supply only over certain land regions such as Europe and the United States. To sound the atmosphere in data sparse areas, new satellite techniques are needed which will produce data in volume for numerical prediction, for GARP (Global Atmospheric Research Program) in the mid-1970's, and for WWW (World Weather Watch), which is already under way.

B. Display of the Refraction Technique

Such a technique was proposed in 1961 by Prof. L. M. Jones of the University of Michigan High Altitude Engineering Laboratory. It consists of probing the atmosphere by measuring the refraction of a star ray passing through with a minimum tangent height (r_o). (Fig. 1). This refraction angle (R_s) is measured by a star-tracker as a function of time (t). From geometric considerations and the fact that the satellite platform is to be highly stable, $\theta(t)$ is obtained. These quantities yield the zenith angle, $z_s(t)$.

Employing Snells' Law, which states that the triple product of the index of refraction (μ), r(t), and sin $z_s(t)$ is constant along the refracted ray path, we find that certain simplifications can be made at the tangent point, where sin $z_s(t) = 0$, and at the satellite, where $\mu \simeq 1$. Therefore

$$r_s(t) \sin z_s(t) = \mu_o r_o(t) \tag{1}$$

Subscript zero refers to the tangent height and $r_s(t)$ is obtained by satellite tracking. $\mu_o r_o$ has been named the impact parameter, η_o, by us.

From knowledge of $R_s(t)$ and $\eta_o(t)$, $R_s(\eta_o)$ is determined. As may be seen in Eq. (2), this function is desired for the computation of μ by numerical quadrature.

$$\mu = \exp\left[-\frac{1}{\pi}\int_{\eta}^{\infty}(\eta_o^2-\eta^2)^{-\frac{1}{2}} R(\eta_o)\, d\eta_o\right] \tag{2}$$

Choosing η, one finds $\mu = \psi(\eta)$ and then secures r from the expression, $r = \eta/\mu$. The remaining relationships used to get the common atmospheric parameters are:

Dale and Gladstone's Law, $\rho = \frac{\mu-1}{K}$ (3)

ρ = density

k = constant

Hydrostatic Law, $\frac{dP}{dh} = -\rho g$ (4)

P = pressure

h = height

g = gravity acceleration

Gas Law, $P = \rho R^* T$ (5)

R^* = gas constant

T = temperature

The ρ- field is expected to attain more importance in the future, but P- and T- fields are nevertheless obtainable from use of the last two Laws, with little error.

C. Details of Star-tracking from a Spacecraft

From a polar orbit which assures global data excepting over the sun-lit pole, the star-tracker is pointed aft and programmed to pick up a star ray penetrating the Earth's dark hemisphere (Fig. 2). First contact is made at 40 - 50 km tangent height, but as the satellite proceeds in orbit, the star appears to set, i.e., it is occulted by the Earth. The measurements of $R_s(t)$, $\theta(t)$, and $r_s(t)$ are made about twice per second, and the size of R_s varies from 4 arc seconds at 50km to 40 arc minutes at 5 km. Successful data-gathering below 5 km is improbable because of cloudiness, which obstructs ray penetration, attenuation due to ray scattering and a prismatic dispersion effect. Keeping the azimuth angles within 30^o of aft conserves tracking time and permits the recording of about 50 R_s values in each of 80 or so scans per orbit. Tracking time is about 30 sec per star. The resulting N. Hemisphere coverage (Fig. 3) for a particular day shows the repetitive pattern. The longitudinal spacing between pattern repetition is about 27^o when the orbital altitude is 1100 km. Clearly, a wealth of upper air data is attainable when stars of magnitudes greater than 4.5 are tracked, as in this case.

The equipment in the spacecraft includes, besides the star-tracking telescope, a clock, a data recorder, and a telemeter. On the ground, a command and data acquisition station would pass updated sets of star coordinates to the satellite. It would also receive data in brief periods amounting to a few seconds per orbit. About 1/4 million bits are involved in these transmissions. A data processing program was written in 1964 which retrieves density, pressure and temperature more than twice as fast as acquired.

D. Theoretical Justification for the Refraction Solution

Eq. (2) is a mathematical inversion of the classical refraction integral for a ray passing completely through the atmosphere with impact parameter η_c. The latter integral is

$$R = 2\eta_0 \int_1^{\mu_0} \frac{d\mu}{\mu (\eta^2 - \eta_0^2)^{1/2}} \qquad (6)$$

The inversion was discovered in the field of seismology, and it has the desirable features of uniqueness and exactness. The uniqueness implies, in the refraction case, that knowledge of the function $R(\eta_c)$ yields any and all densities within the scan altitude limits. The two features combined permit (1) simple, precise evaluation of $R(\eta_0)$, (2) direct reduction of simulated $R(\eta_c)$ data to ρ, P, and T, and (3) definitive evaluation of errors.

E. Analysis of Errors

The following possible errors have been investigated: (1) measurement of refraction angle at the spacecraft; (2) truncation of pressure at an upper level; (3) nonspherical stratification of the refraction angle about the tangent point; (4) satellite tracking inaccuracy. They will now be considered in turn.

(1) Using the CIRA 1961 atmosphere as a model, Eq. (6) was evaluated numerically to obtain a set of refraction angles. Various Gaussian-scatter standard deviations were then tested, retrieving ρ, P, and T to compare with the model. The second star-tracking parameter which affects the data reduction is readout frequency. Accordingly, this quantity was also varied in the analysis.

(2) When using Eq. (4) to retrieve P(h), an initial estimate of P (or T) is required at the uppermost level where results are to be secured. As one proceeds downward in the integration process, an error in the initial estimate of P will "integrate out" in about 10 km, i.e., it will be overshadowed by the refraction angle measurement errors.

(3) Within the visual and near-IR range of wavelengths, the refractive effect is concentrated quite well at the ray tangent point. This result has been found by an analytic treatment of the lower spacial derivatives of ρ and T around the tangent point under the influence of extreme atmospheric gradients. Thus the refraction angle is found to be symmetric around the tangent point, with negligible departures. To be otherwise would violate one of the basic assumptions of the classical refraction equation.

(4) Since the meteorological parameters obtained from refraction data are, to some extent, averaged values over tens of kilometers in a network which usually has several hundreds of kilometers between observation points, horizontal errors in satellite positioning can be tolerated of the order of 10 km. However, inaccuracies in vertical positioning are transmitted undiminished as height errors into the P- and T-profiles. The P-profile

is especially sensitive to this effect, although the error is systematic in the horizontal and can probably be removed through calibration with radiosoundings.

Numerical results for the error analysis are presented in Figs. 4 and 5 for T-errors and P-errors. The scatter of the refraction angle has a standard deviation of 4 arc seconds, and a 5% RMS pressure error is assigned to the initial value of P at 40 km in both instances. The outcome is entirely comparable in accuracy to radiosondes, indicating that a viable system is assured if the equipment specifications of Figs. 4 and 5 are met. The accuracy requirements for T and P compiled recently by COSPAR Working Group Six for GARP are somewhat more stringent in the lower stratosphere, probably demanding a 2 arc second star tracker to fulfill them.

F. Adverse Atmospheric Effects

A study of atmospheric effects known to operate upon the stellar image received at the satellite has yielded assessments of such diverse factors as (1) molecular scattering, (2) differential refraction (the phenomenon of prismatic dispersion), (3) absorption by gaseous constituents, (4) scintillation, (5) quivering, and (6) clouds.

(1) Molecular scattering has a notable dependence upon wavelength (λ) in the range 0.3 to 1.0 μ. The transmission factors for various λ in this range are shown in Fig. 6 for tangent ray heights between 5 km and 40 km. An analytic model atmosphere was investigated to obtain these results, following the analysis of an isothermal atmosphere.

Water vapor can add important attenuation due to scattering. Its occurrence is largely confined to layers below 10 km, although water vapor penetrates above this level in significant quantities at times, mainly in the tropics.

Dust is another important scatterer because of its tendency to stratify at times in the stratosphere.

(2) Differential refraction shows little wavelength dependence (Fig. 7). However, it is responsible for some of the shifting in the image's center of gravity during occultation. As may be seen in Fig. 7, the transmission suffers a rather great diminution from 30 km to 10 km. Satellite altitude is of major importance in this respect, with a lower orbit enjoying higher transmission. The altitude used here is 1100 km.

(3) Absorption by ozone in the Chappuis band centered near 0.6 μ was found to be inconsequential. This constituent is the principal absorber in the visual range.

(4) The scintillation, or fluctuation of starlight intensity, is related to the telescopic aperture, zenith angle, and meteorological conditions along the ray path. The star-tracker must have an aperture large enough to control adverse scintillation, as the other two factors are not controllable.

(5) Quivering of the stellar image turns a point image into a spot with a diameter of 2 - 4 arc seconds. It is also controlled by a sufficiently large lens size.

(6) Through the collection of thousands of aircraft reports at 10 - 12 km, the vertical distribution of clouds has been better determined by us. With a few exceptional cases, it is generally true that clouds will not interfere with refraction scans down to 10 km. The principal exception is the Intertropical Convergence Zone of tropical latitudes; a second is certain instability lines in low- and middle-latitudes. Lower probing down to about 5 km is often not restricted by clouds, but is impared by the other adverse effects.

G. Signal/Noise Ratio

The reduction of the signal received behind the photocathode tube may be summarized in a graph of photocathode magnitude against tangent ray height (Fig. 8). Thus, taking into account the spectral response of two sensors, as well as molecular scattering, differential refraction, and ozone absorption, a decline in apparent stellar magnitude is to be expected amounting to 5 to 7 when tracking down to 5 km.

The noise consists of 4 components. They are the airglow, which predominates; zodiacal light; aurorae; and stellar background. Minimum noise levels have been computed for these factors, excluding the highly variable aurorae, which generally lie above the field of view.

Signal/noise ratios were calculated for equipment specifications, utilizing the above information.

H. Downward Extrapolation to 500 mb.

Recognizing the difficulty of retrieving the atmospheric parameters at the critical 500-mb level (~ 5.5 km) by the refraction method,

error studies were completed dealing with downward extrapolation of the data obtainable at higher levels. Outside of the tropics, 90 percent or more of the variance of the 500-mb geopotential is explained by an extrapolation from 300 mb (~ 9 km) in January, slightly less in July, and 50 - 80 percent of the variance is explained when extrapolating from 200 mb (~ 12 km) to 500 mb. Furthermore, these values are upheld, outside of the 0^{o} - 20^{o} latitude band, when the regression coefficients are all expressed as functions of latitude. This work was completed for one-half of the N. Hemisphere.

II. Supporting Theoretical Analysis

During the contract period, supporting studies have been conducted to assist with hardware design. Generally, the results are incorporated into engineering decisions. Two results have application to the technique theory and are of independent interest. They have not been otherwise published and are presented here for documentation purposes.

A. The Spacial Autocorrelation in Objective Analysis

Introduction

The kind of information obtainable from stellar refraction is similar to that which is currently produced by radiosondes, but two important differences in air-sampling locations should be noted. First, the data from star-tracking would be mainly from the upper troposphere and lower stratosphere, in the upper altitude range of radiosoundings. Second, the geographical locations of refraction data points would not be fixed, in the sense that land-based radiosonde stations are fixed. The latter difference leads one to consider how to incorporate such data into charts being analyzed objectively, as by a computer program. If the data are to help form the basis for a field of grid values, as is commonly the case, then the question can be enlarged to include all kinds of measurements pertinent to the parameter being analyzed.

Some recent advances in the field of objective analysis have been made by Gandin [1963] , Peterson [1967] , and Alaka [1969] . In all of these investigations, the method of "optimum interpolation" holds a prominent place among the various schemes to give data values appropriate weights when transferring data to grid points. Kolmogorov 1941 is credited with the origination of the idea of "optimum interpolation" and Gandin is responsible for much of its development. Kruger's unpublished comparative study of four methods, namely, those of Gandin, the National Meteorological Center in Washington, D. C., and (two) of the Canadian Central Analysis Office showed "optimum interpolation" to be about on a par with one of the Canadian methods and clearly superior to the other two, in sparse data regions.

In the "optimum interpolation" method, the weighting functions are obtained by autocorrelation techniques and they are applied under the assumption that the meteorological fields are homogeneous and isotropic with respect to the spacial autocorrelation function. Mathematically, this means that for homogeneity,

$$\left[f'\ (\vec{r}_i)\right]^2 = \text{constant for all i,} \qquad (1)$$

and for isotropy

$$\frac{\partial f'(\vec{r}_i)}{\partial \theta} = \text{constant for all i.} \qquad (2)$$

f' = deviation of an element from its norm

$\vec{r}_i$ = point vector on the isobaric surface

θ = degrees from north on the isobaric surface

Since these assumptions are basic to "optimum interpolation" and an intensive search did not reveal any published test results in the literature, an examination was conducted on 500 mb height data for three sites in the Northern Hemisphere. The purpose of the test was to find, through graphical displays, the degree of homogeneity and isotropy apparent in the data.

Grid Network and Data

A grid-point network was used which had a 500 km separation between points at the three sites selected. 500 mb height data* for the Januarys of

* Sometimes referred to as Project 433-L grid data.

of 1956, 1957, and 1958 were processed, the data consisting of interpolated grid-point values from subjectively analyzed charts of the National Weather Analysis Center. The information was available on punched cards, and no expense was incurred in this respect. July data were also processed for the same years, but for one site, only.

Computation of the Spacial Autocorrelation Coefficient

The spacial autocorrelation function, $\mu(\rho)$, was normalized, as may be seen in the following expression,

$$\mu_j(\rho) = \left[\frac{1}{N}\sum_{i=1}^{N} \Phi_{ij}\Phi_{io} - \Phi_j\Phi_o\right]\left[\sigma_j\sigma_o\right]^{-1} \qquad (3)$$

where $$\sigma_j = \left[\frac{1}{N}\sum_{i=1}^{N} \Phi_{ij}^{\,2} - \left(\frac{1}{N}\sum_{i=1}^{N} \Phi_{ij}\right)^2\right]^{1/2}$$

ρ = distance from base point

N = 186 observations

Φ = geopotential height

σ = standard deviation of

subscript zero refers to base point, or "site"

subscript j refers to grid-point

The sites selected were as follows, and will be referred to by site number.

1. (42N, 101 W), in Nebraska, U.S.A.
2. (46N, 35W), 1550 km east of Newfoundland in the Atlantic Ocean

3. (60N, 125W), near Fort Nelson, British Columbia

From each base point, the μ_j were computed by an IBM 7090 to a distance of 5800 km (Site 1), 4700 km (Site 2), and 3800 km (Site 3), excepting in those directions where data boundaries cut off the calculations.

Results

The μ_j were displayed in three ways. The first mode of representation can be found in Gandin's book, p. 49, as a collection of curves of μ against ρ. However, the scatter was not shown therein, and it is envidently rather large beyond 500 km at Sites 1 and 2 (Figs. 1, 2) and even at 500 km at Site 3 (Fig. 3). The curves drawn on these figures were fitted by inspection to a standard empirical formula , $\mu(\rho) = e^{-a\rho} \cos(b\rho)$.

The large amount of scatter in these diagrams was studied further through curves of μ versus ρ for 8 directions from the base point (Figs. 4, 5), and two-dimensional displays of $\mu(\rho)$ centered upon the base point (Figs. 6-9). True homogeneity and isotropy would be indicated by coincident curves and concentric circles, respectively, in these two types of figures. Qualitatively, rather large departures from homogeneous and isotropic conditions are quite evident to all sites in these graphs. No quantitative measure of these statistical concepts was found in the literature, however, so here the matter rests. There is tenous evidence of relationships between the patterns of Figs. 6-9 and the mean flow fields at 500 mb for the same periods. More base points need to be explored to firmly establish such relationships.

Conclusions

The assumption of statistical isotropy and homogeneity in geopotential

height data at 500 mb, as defined by Eqs. 1 and 2, is not on firm ground. Diagrams of the normalized autocorrelation coefficient, $\mu(\rho)$, show departures from true isotropic and homogeneous conditions at three widely separated base points in the Northen Hemisphere. These results relate particularly to the method of "optimum interpolation" in objective analysis, which employs the above assumption in forming spacial fields of $\mu(\rho)$.

References

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Gandin, L. S., Objective Analysis of Meteorological Fields, GIMIZ, Gidrometeorologicheskoe Izdatel' stvo, Leningrad, 1963.

Kolmogorov, A. N., Interpolated and Extrapolated Stationary Random Sequences, Izvestiya AN SSSR, Seriya Matematicheskaya, 5, 1, 1941.

Peterson, Daniel, A Study of Interpolation and Smoothing Operators in Objective Analysis, EE 148 DC 7 35028, New Mexico U., Bureau of Engineering Research, 15 December 1967.

B. THE DISTRIBUTION OF BRIGHT STARS OBSERVABLE FROM A SPACECRAFT ORBITING THE EARTH AT A SMALL INCLINATION ANGLE

When only the brighter stars can be tracked in an occultation experiment, as is presumed to be true for manned capsules, the distribution of available stars is inevitably uneven and weighted heavily toward Gould's Belt. A computer program at hand based upon a magnetic tape version of the Albany (Boss) Catalog was used to obtain an accurate estimate of this distribution. Inputs for the IBM 7090 program were the orbital elements of the satellite and the celestial coordinates of stars brighter than magnitude 2.0. The output was the geographical position of stars observable on the night side of Earth within 30° of due aft.

The two launch dates selected for testing were March 21 and September 21, both midnight launchings. The orbital inclination was 27° in either case, this being the estimate for Apollo Applications A at that time. The resulting geographical positions were plotted on a global chart, and the following features were noted.

March 21 launch: 12 stars were located, all clustered in the Indian Ocean - Western Australia region of the Southern Hemisphere. The probable lack of routine radiosonde reports in this region was considered to be quite disadvantageous, as a comparison of stellar refraction data (in terms of density and temperature profiles) with a radiosounding would be desirable.

September 21 launch: 4 stars were located near 20°N in the Western Hemisphere. These data points were more amenable to radiosonde comparison,

especially the ones near the Dominican Republic and Hawaii.

The conclusion reached by this investigation is that a fraction of stars brighter than magnitude 2.0 will be available for tracking on the night side aft of the spacecraft, even in an orbit of low inclination. However, in tropical regions a large proportion of the stellar refraction profiles, and their corresponding atmospheric parameter profiles, would not be close enough to a radiosonde station to permit a comparison test. Thus if this kind of test is desired, careful preplanning is needed with attention being given to launch date, time of attempted observation, and upper cloudiness forecasts.

III. Hardware Requirements

A. General

Having thus shown the meteorological import attached to refraction angle measurements of the type mentioned, and having conducted a definitive error analysis, the overall performance specifications were set and the task of designing a state-of-the-art star-tracker was begun.

The performance goals, overall, may be summarized:

Star-tracking with angular error less than 2 arc-seconds RMS.

Readout frequency greater than 10/second.

Acquisition of any star brighter than the third visual magnitude.

Tracking of any star brighter than the 4.5 visual magnitude when attenuated an additional 5 magnitudes, with stated accuracy.

Operation from astronomical twilight to astronomical twilight on the dark side of any orbit.

Continued tracking through any cirrus layer causing occultation of less than 0.5 second.

B. Major Subsystems

The major subsystems involved are:

Acquisition telescope

Data telescope

Acquisition tracker

Data tracker

Gimbals

Gyro

Command logic unit

Astronaut control unit

A description of the primary requirements is given for each subsystem:

1. Acquisition telescope

   Field of view - 2^{o} (or more)

   Transmission - 60%

   Refracting optics

   Diameter - 2.5 inch

   Shutter to prevent contamination

2. Data telescope

   Field of view - 16 arc-minutes

   Diameter - 10 inches

   Transmission - 60%

   Reflecting, folded or catadioptric optical system

   Thermal gradient control of folded optics

   Shutter to prevent contamination

3. Acquisition tracker

   F 4012, S20 phototube (image dissector) with .020 square aperture

   Square raster scanning system with 10% overlap

   Atwill scanning detector system

   Error signal (Atwill) generation at 200 Hz

   Error signal error (Atwill) less than 3% in either axis

4. Data tracker

F 4012, S20 phototube (image dissector) with .020 square photo cathode

Square raster scanning system with 10% overlap

Atwill scanning detector system

Error signal (Atwill) generation at 200 Hz

Error signal error (Atwill) less than 3% in either axis

5. Gimbals

Two-axis freedom

No static friction permissible

Allowable spring torque = -5 lb-in/radian

Caging requirement for launch and astronaut boresight coincidence

Torquing capability to maintain required pointing accuracy under prescribed star angle acceleration plus spacecraft acceleration

6. Gyro requirements are detailed in the Star-Tracker Specification, below.

7. Command Logic Unit:

Upon astronaut command to track, the logic must:

a) Select the brightest star in the acquisition telescope field-of-view by raster scanning and memorize its position.

b) Point the telescope so as to center the image in the field-of-view.

c) Switch to Atwill scan and center the image precisely.

d) Begin raster scan in data tracker.

e) Upon location of image in data tracker switch gimbal control to data tracker

f) Point telescope to center image in the data telescope field-of-view.

g) Switch to Atwill scan and center the image precisely.

The above sequence should take less than three seconds.

8. Astronaut Control Unit

This Unit will be located in the Command Module and will be comprised of a zero-reader, switches, and boresighted telescope.

It enables the astronaut to warm-up the equipment, select a star and point the spececraft so as to acquire it, command the tracker to track and monitor shut-down or occultation, and secure the equipment when finished.

This Unit cannot be designed until the interfaces are defined and ICD' s issued.

IV. Phase C Summary, Conclusions & Recommendations

A. Chronology of the Experiment Technique

1. The refraction star-tracking technique was conceived in 1961 and feasibility studies began in 1962.

2. The analytic solution of density as a function of height from measurements of refraction angle was demonstrated in 1964.

3. Error analyses were completed in 1965.

4. Experiment definition studies were carried out in 1965 and 1966 and 1967.

5. A Phase "C" proposal was submitted on 9 June 1967 for equipment to be flown on the Apollo Applications A mission.

6. A contract was awarded on 6 September 1967 (NAS 9-7457) for a portion of the proposed Phase "C" effort, excluding the construction of a qualifiable prototype, and including a brassboard instrument. A six-month period was indicated.

a) During the contract period the anticipated funding for Phase "D" was sharply reduced and the time schedule was drastically stretched.

b) During the contract period the spacecraft integration contract was cancelled. Because of this, the carrier vehicle was not designed and the interface control documentation was not issued.

c) During the contract period the flight mission was cancelled.

d) The University, working in close harmony with the Manned Spacecraft Center, proposed stretching the NAS 9-7457 contract period to 1 July 1968 with no cost increase. This request was granted.

e) The University was advised to proceed with the design in as reasonable a manner as possible, considering the lack of interface control. NASA supplied interface design parameters and approximate design details.

f) As 1 July 1968 approached it was evident that follow-on funding would not be available on that date. Accordingly, the Principal Investigator redoubled efforts to complete the engineering design and brassboard construction to a milestone point prior to the loss of personnel. This was accomplished. As a result, the planning documents for the cancelled mission, which were clearly of diminished importance, were deferred and completed by the Principal Investigator after the loss of other project personnel.

7. As of 14 March 1969:

a) The key personnel are on leave of absence from the University activities. Non-key personnel have been discharged. The Principal Investigator is employed on a different, related contract on another project.

b) The brassboard and mockup hardware items are completed and located in the University star-simulation facility. It has been formally requested that they remain in the University

NASA facility property account pending a resumption of hardware implementation for flight.

c) The documentation has been completed and is being delivered in March 1969.

B. Contract Effort Summarized

The bulk of contract effort was expended in the design and fabrication of the brassboard prototype instrument. This effort may be roughly divided into five categories:

Supporting theoretical analyses

Background analysis and critical systems engineering decisions

Critical component selection

Detail electronic design and fabrication

Detail mechanical design and fabrication

1. Supporting analysis is included inthe remainder of the report, such as Figs. 18, 19, 20, or in Section II above.

2. An extremely critical decision on the overall system was required. The measurement of refraction angle can be made by comparing the present location of a star with its former unrefracted location by means of an inertial reference (gyroscope); or it can be done by including both the subject star and an unrefracted star in the field-of-view, and measuring the change in angle between them as the first is refracted. The former method requires a telescope in gimbals and gyros; the latter, a large field-of-view with certain pattern recognition features, great resolution and rapid scanning, but no gimbals or gyros. We refer

to the latter as "electronic gimballing". The electronic gimballing can be used on one star, with gyros but no gimbals, or if the spacecraft motion were known (as through auxiliary star trackers) on one star with no gyros and no gimbals.

The decision to proceed with a conventional gimballed telescope and gyros was made after a great amount of study, analysis, consulting help, investigation of test results, and comparisons with operating instruments. Electronic gimballing was very attractive because of its simplicity and consequent economy. However, the required accuracy lay somewhat beyond the anticipated state-of-the-art at the time of Phase 'D" implementation. Improvements in electronic gimballing were occurring rapidly, therefore the time of Phase "D" implementation played an essential role in what otherwise would have been a straightforward engineering decision.

Having been now indefinitely delayed, the Phase "D" schedule may some day dictate that due to advances in electronic gimballing the current design is not optimum. Such vagaries could not and were not considered by the designers.

3. Other important but less critical decisions involved the selection of gimbal bearings, phototube type, basic telescope optical design, and gimbal torque motor size. These component selections were rather fundamental to the systems design.

Once the phototube type was chosen for performance characteristics based on supporting analysis of spectral characteristics of starlight

having passed through the atmosphere on a tangent path, and the optical system was chosen, the gimbal bearings and torque motor sizes were chosen from error rate network analyses.

The approach to such analyses is illustrated by an example in figures 18 through 32. Supporting analysts calculated average probable refraction angles, rates, accelerations, and times for a typical occultation, as shown in figures 18, 19, and 20. The telescope and star-tracker system characteristics were simulated by the systems in Figures 21 and 22. The error rate network design procedure is shown in figures 23 through 30. Then, knowing the Apollo stability limit cycle in the fine control mode and the minimum attitude stabilizing thrust (15 ms linear duration to produce 6 arc-minute/sec rate change), the transient response of the overall system is shown in figures 31 and 32.

By use of such an approach, the flex-pivot was chosen over such possibilities as ball-bearings and the 60 oz-in torque motor was selected. The size of flex-pivot was likewise determined, although based on a 1g test demonstration. If 0 g conditions were assumed the specification could have been less rigid, but the instrument would not have been susceptible to ground performance test.

4. The electronic circuit design and some construction details are illustrated in the attached specification drawings.

5. The mechanical design is illustrated in the attached specification photographs and drawings.

C. Conclusions

1. The brassboard instrument was successfully designed and constructed. It was not completely tested. Sweep circuitry and command logic was tested and performs according to expectation. The alignment of sweep with aperture at telescope focus was not accomplished satisfactorily and requires adjustment rather than redesign. The servo system is analytically correct but has not been tested with simulated star motion.

2. The planning functions were completed. Because of the lack of firm interface controls some documents are preliminary. The cancellation of the proposed mission greatly diminished the interest in and value of these documents.

3. The very rigid performance requirements were met in the design somewhat more readily than had been anticipated. This has increased the feasibility of the technique.

4. The failure to provide a follow-on contract for flight equipment has threatened the permanent loss of the project of several key persons.

D. Recommendations

1. The brassboard instrument should be thoroughly tested in the University star-simulation facility. Its performance has a potential impact on star-tracking technology as well as the refraction technique.

2. The stellar refraction technique remains at this report date the only technique seriously proposed which can obtain unambiguous,

accurate, atmospheric structure data by remote sensing. Its cloud cut-off altitude of 300 to 500 mb appears to be insufficient reason not to utilize the technique for structure of the atmosphere from that level to 24 km, in view of its unique advantages.

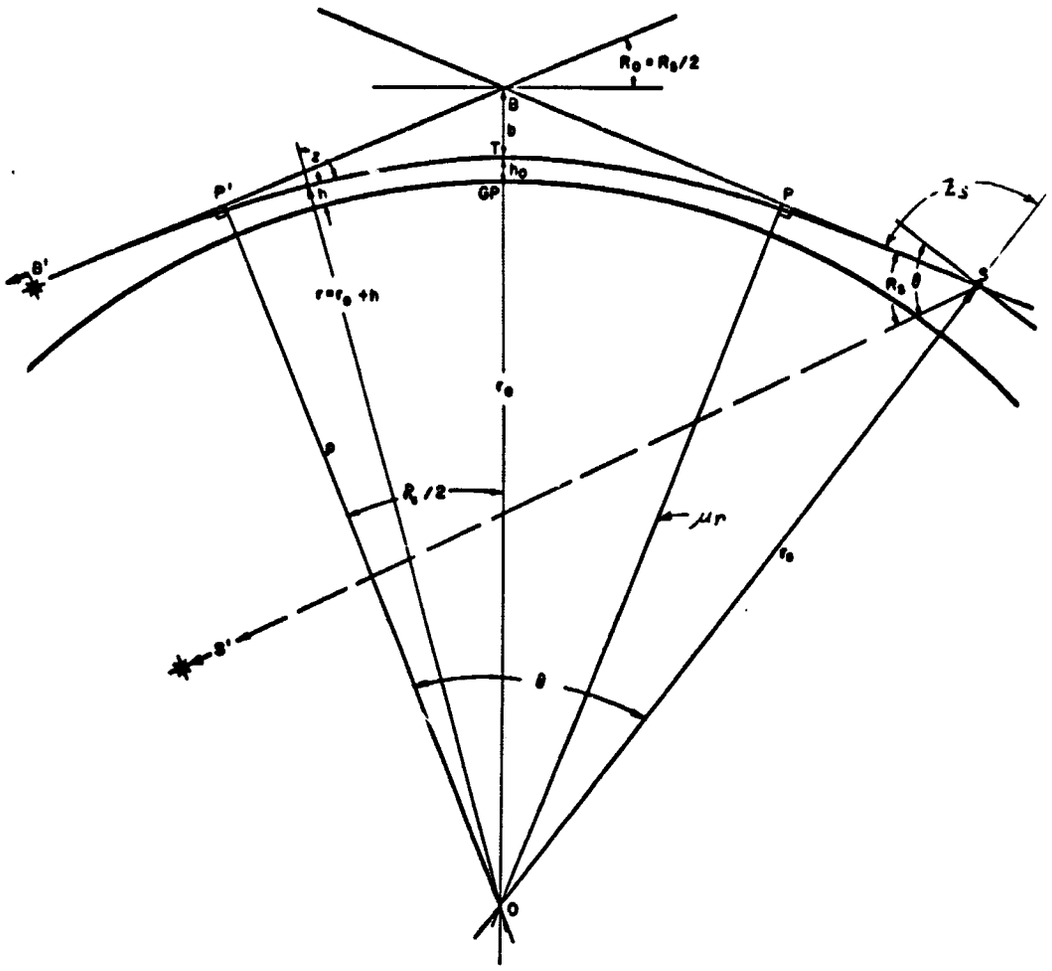
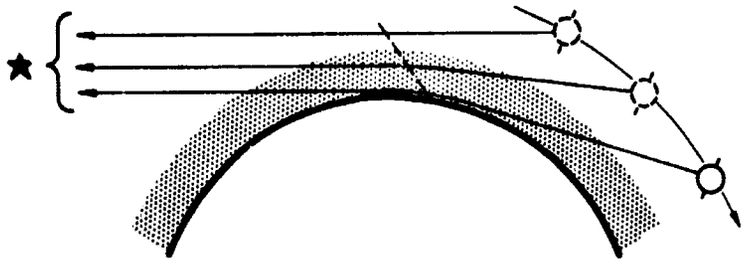
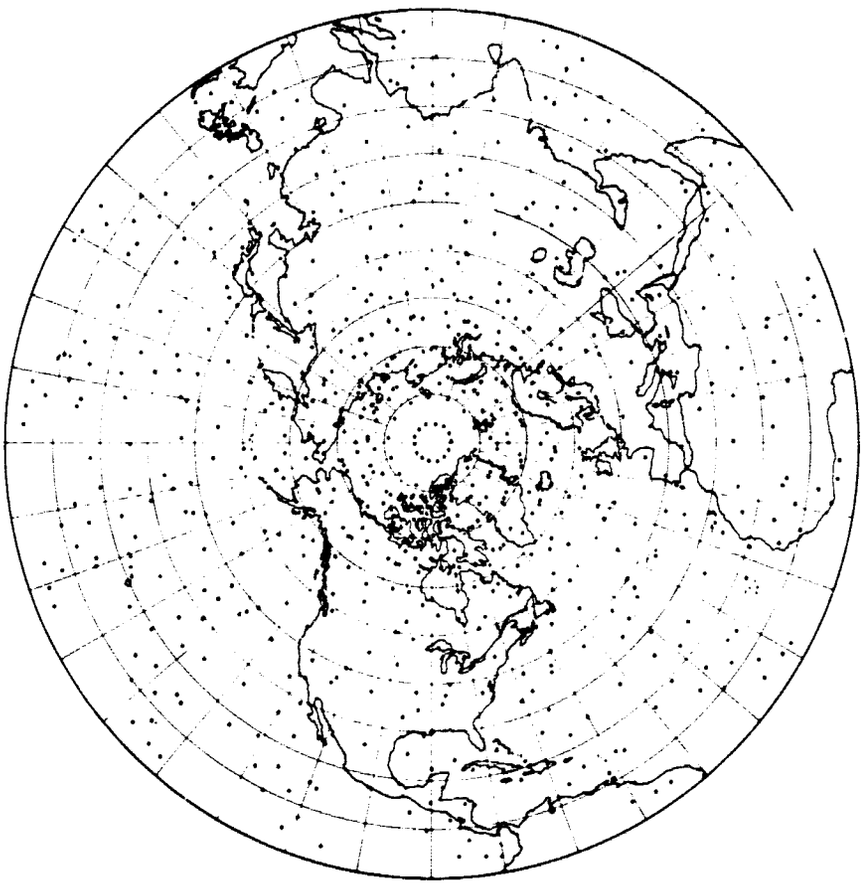


Fig. 1 Geometry of refraction.



SCHEMATIC ILLUSTRATION OF A REFRACTION SCAN

Figure 2



EACH DOT REPRESENTS AN ATMOSPHERIC SOUNDING.
OBSERVATIONS FOR A 24 HOUR PERIOD ON DEC. 21
1100 KM, CIRCULAR, SUN-SYNCHRONOUS ORBIT.
SINGLE TELESCOPE.

Figure 3

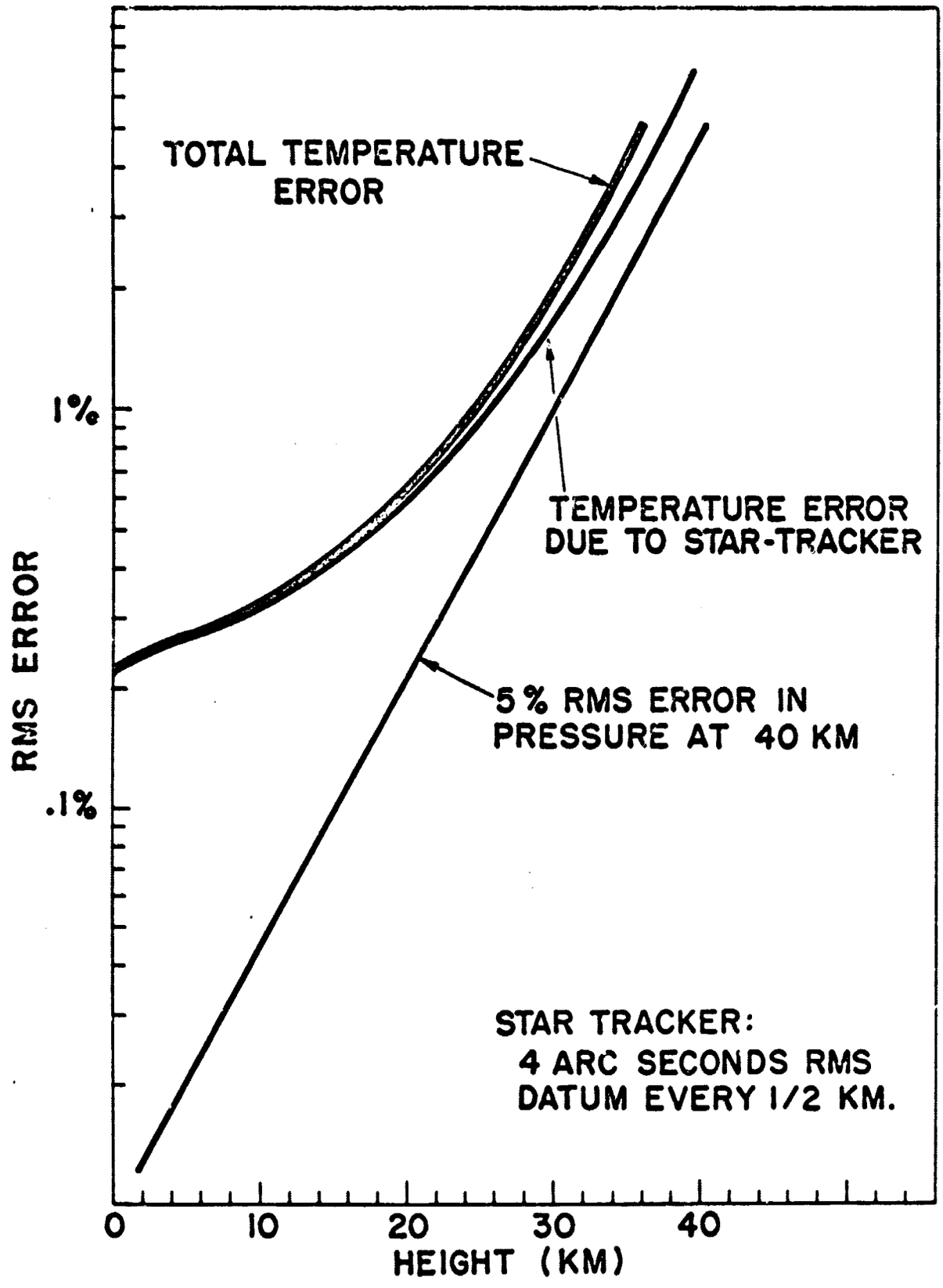


Fig. 4 Total temperature error for 4-arc-second star-tracker.

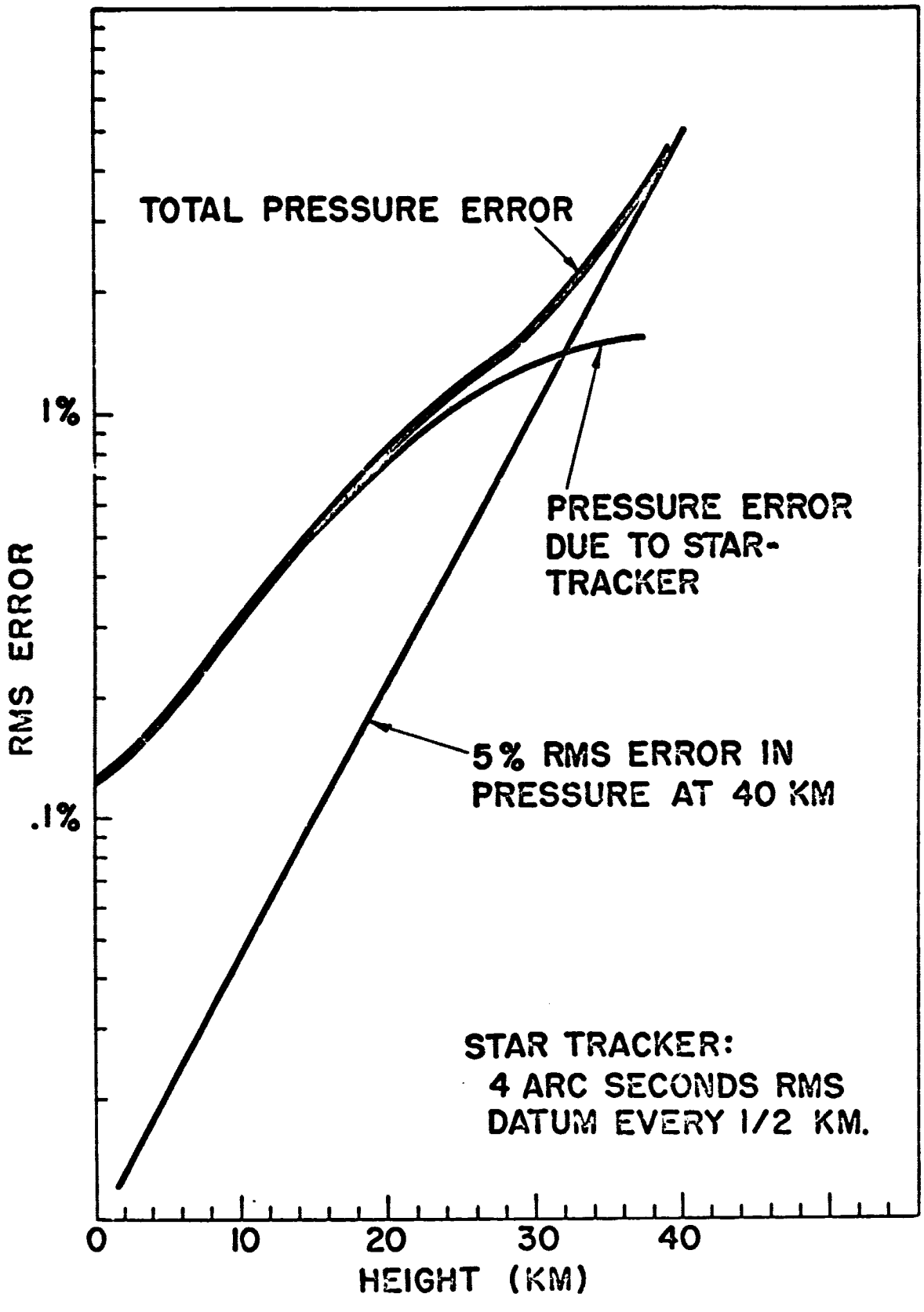


Fig. 5 Total pressure error for 4-arc-second star-tracker.

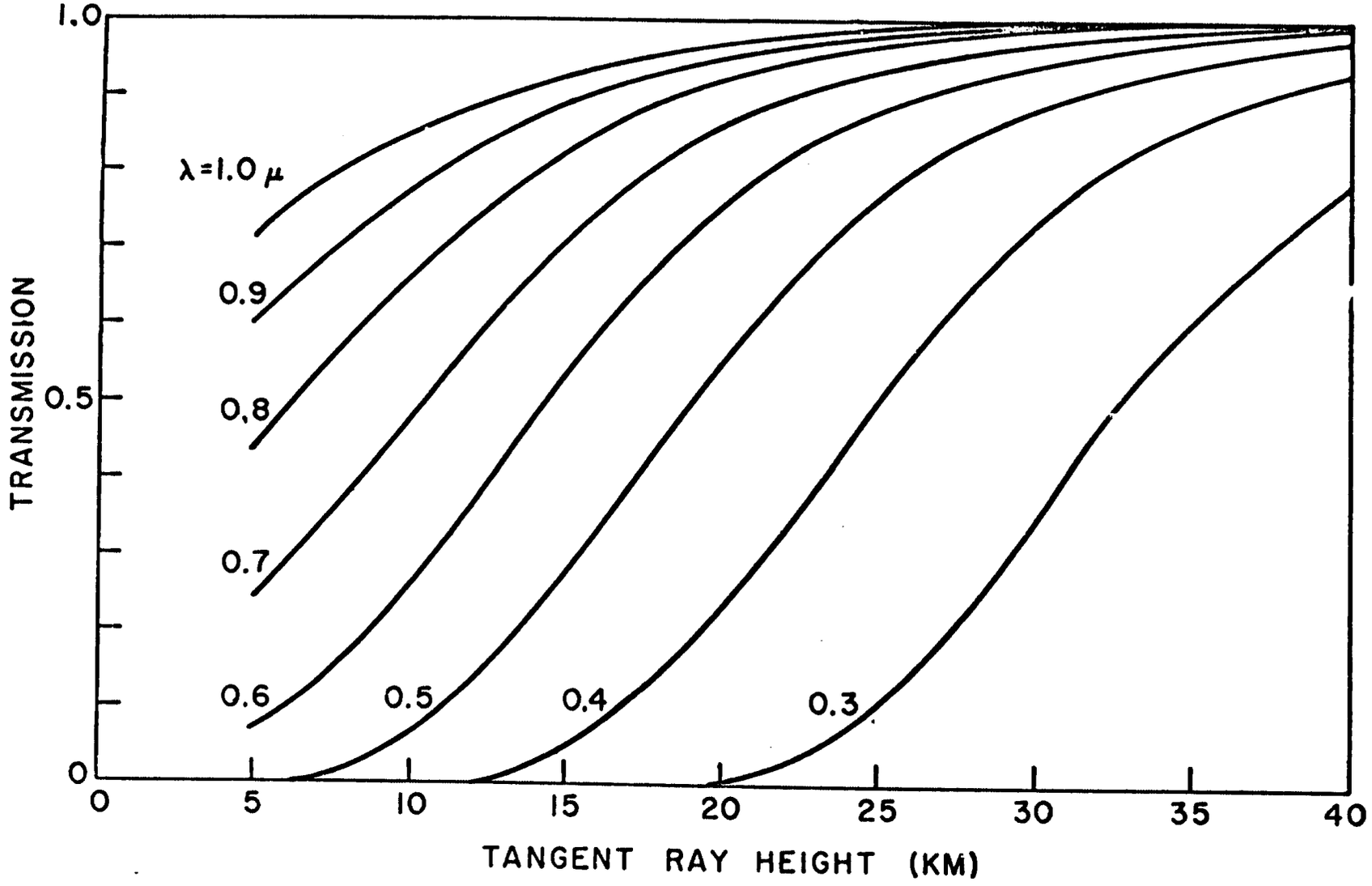


Fig. 6 Intensity reduction due to molecular scattering in an analytic model atmosphere.

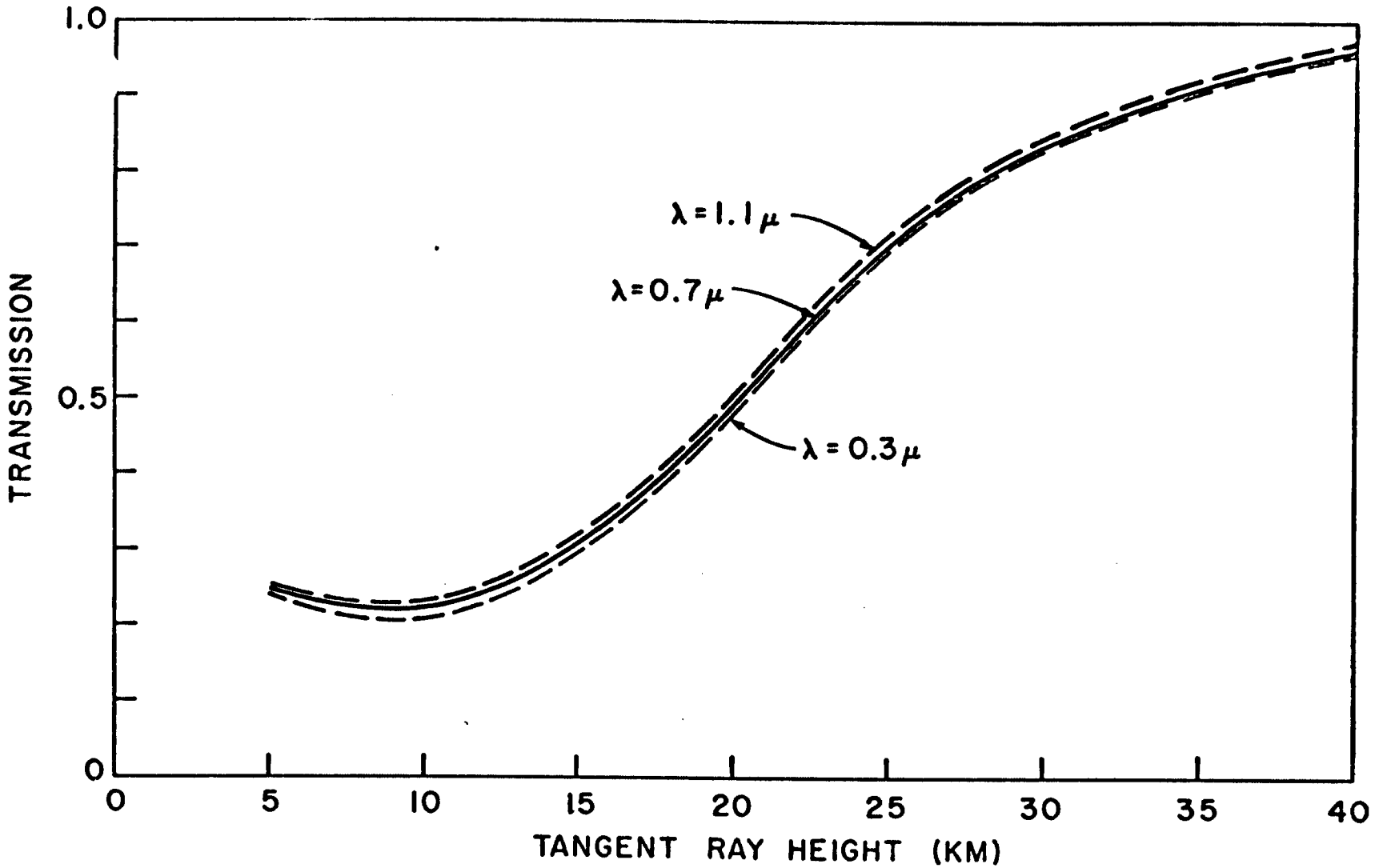


Fig. 7 Intensity reduction due to differential refraction in an analytic model atmosphere.

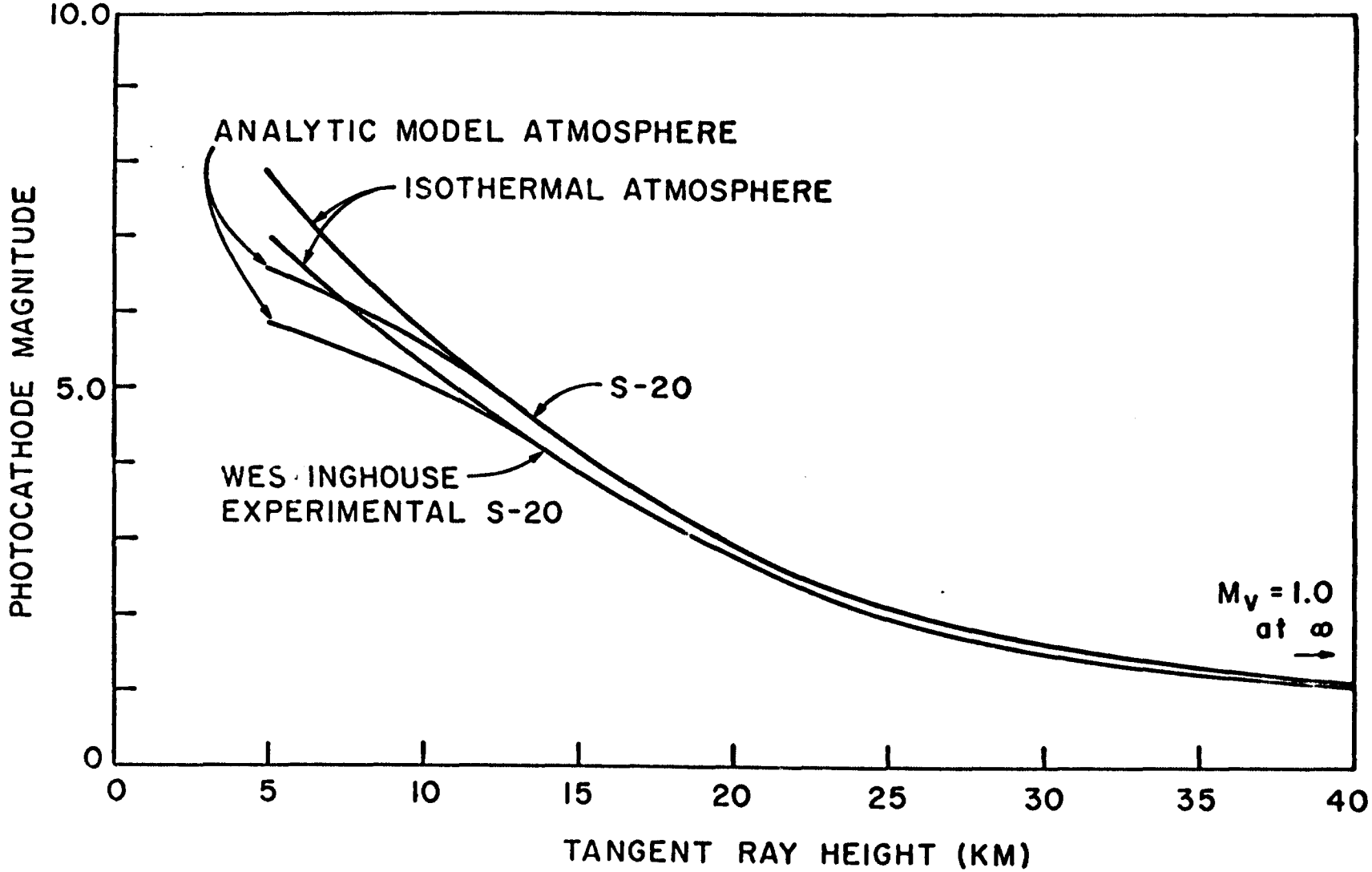


Fig. 8 Photocathode magnitude as a function of tangent ray height for the S-20 and Westinghouse Experimental S-20. The initial photocathode magnitude of +1.0 is arbitrarily assigned equal to +1.0 visual magnitude. The spectral type is G0.

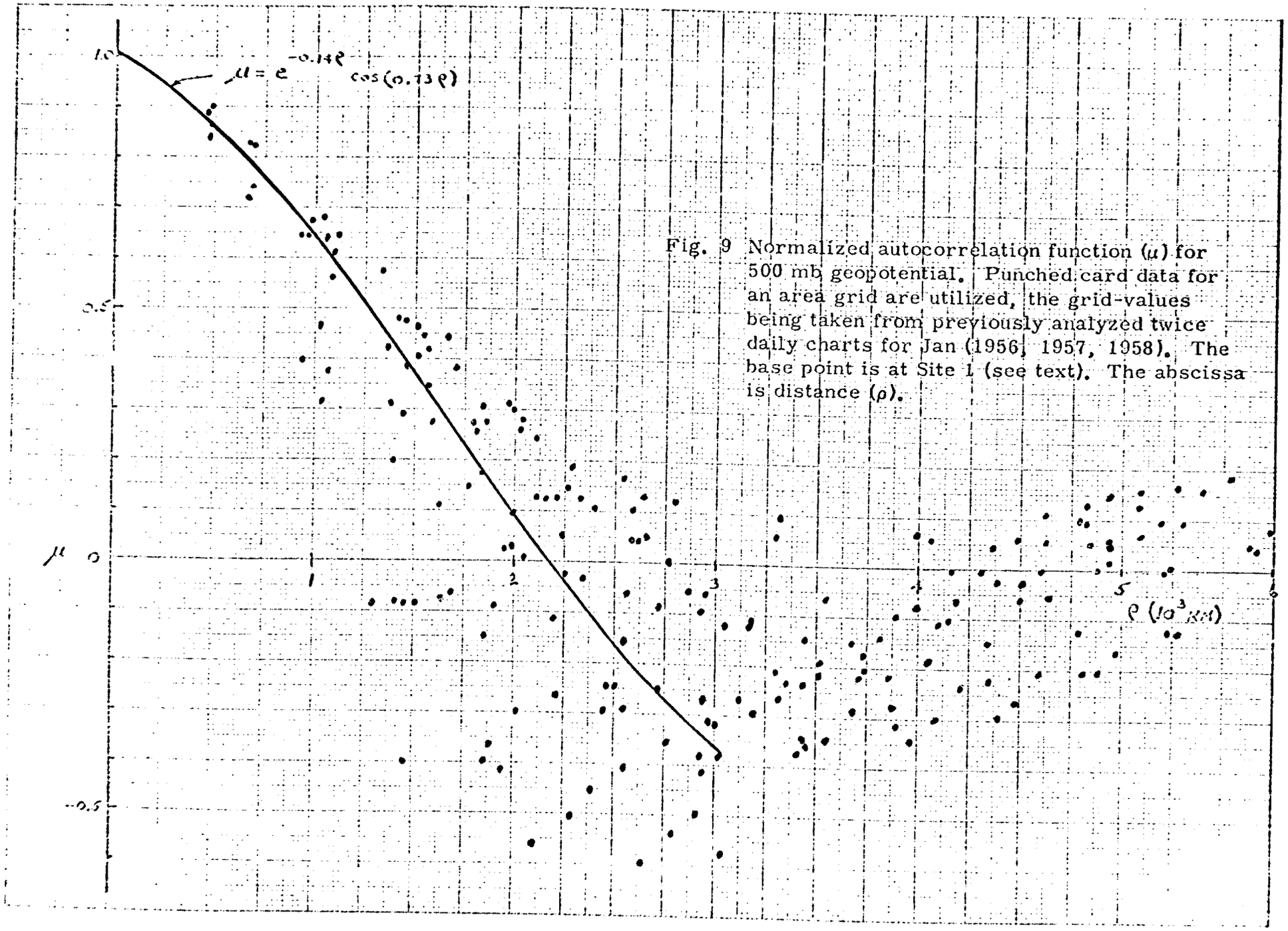


Fig. 9 Normalized autocorrelation function (μ) for 500 mb geopotential. Punched card data for an area grid are utilized, the grid-values being taken from previously analyzed twice daily charts for Jan (1956, 1957, 1958). The base point is at Site 1 (see text). The abscissa is distance (ρ).

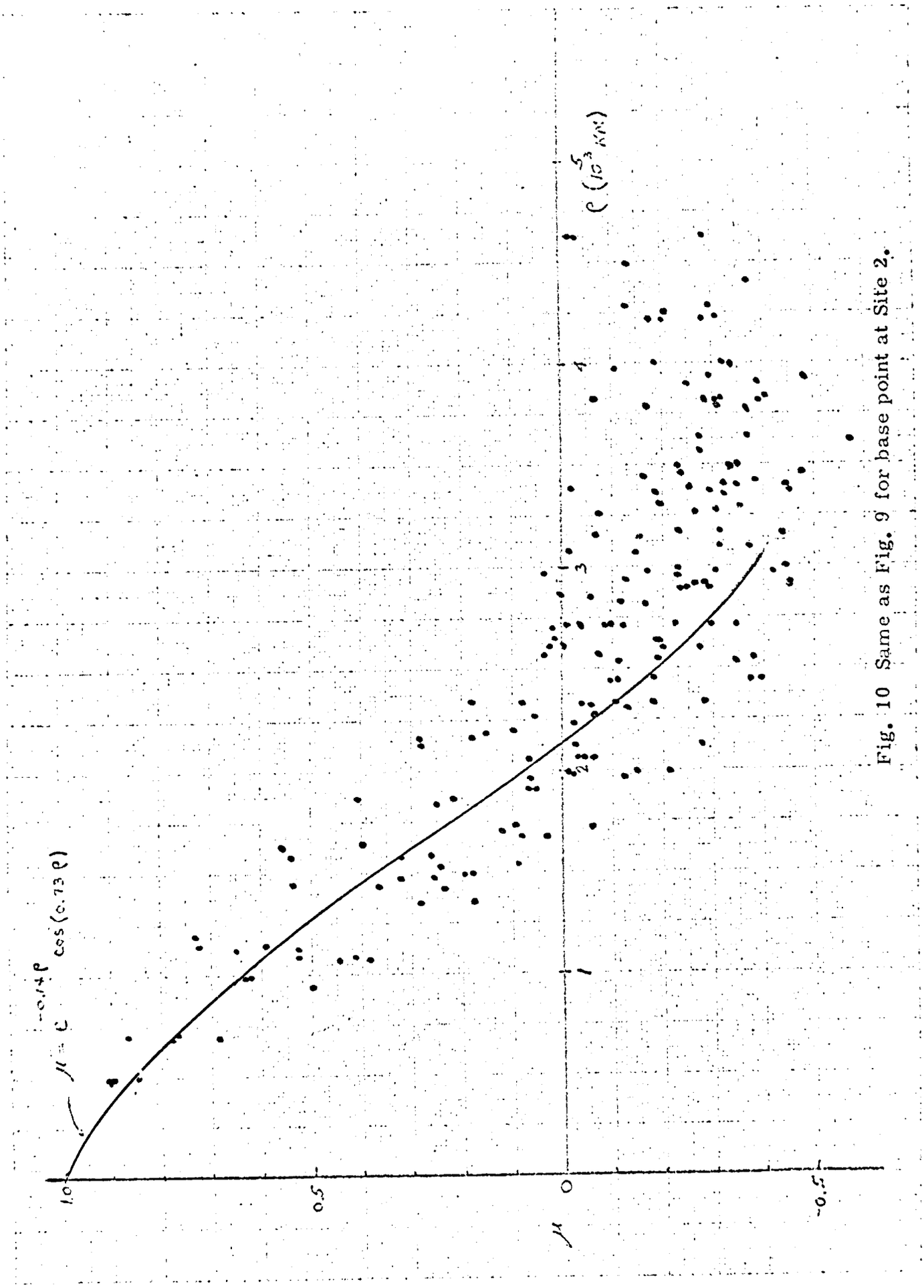


Fig. 10 Same as Fig. 9 for base point at Site 2.

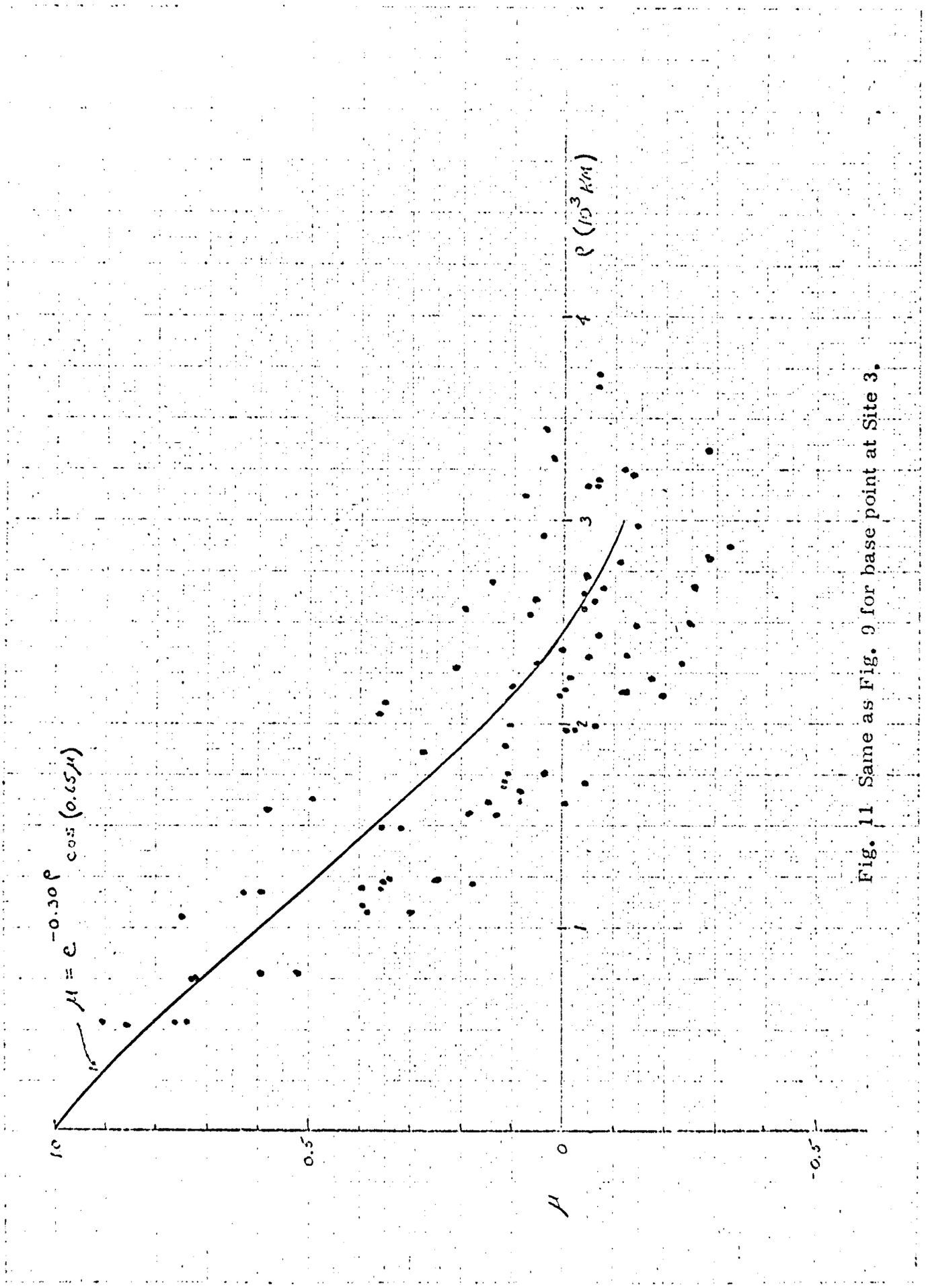


Fig. 11 Same as Fig. 9 for base point at Site 3.

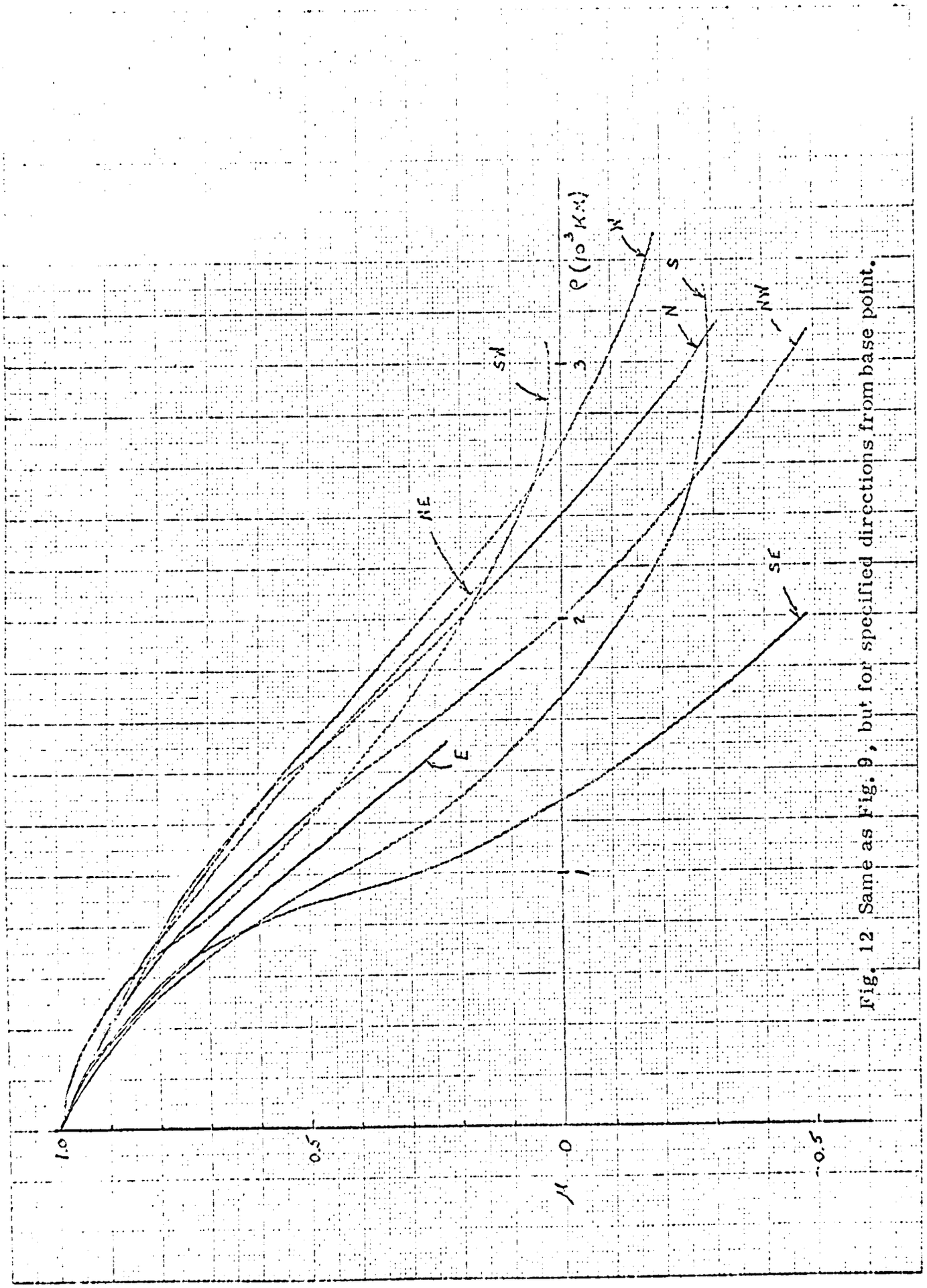
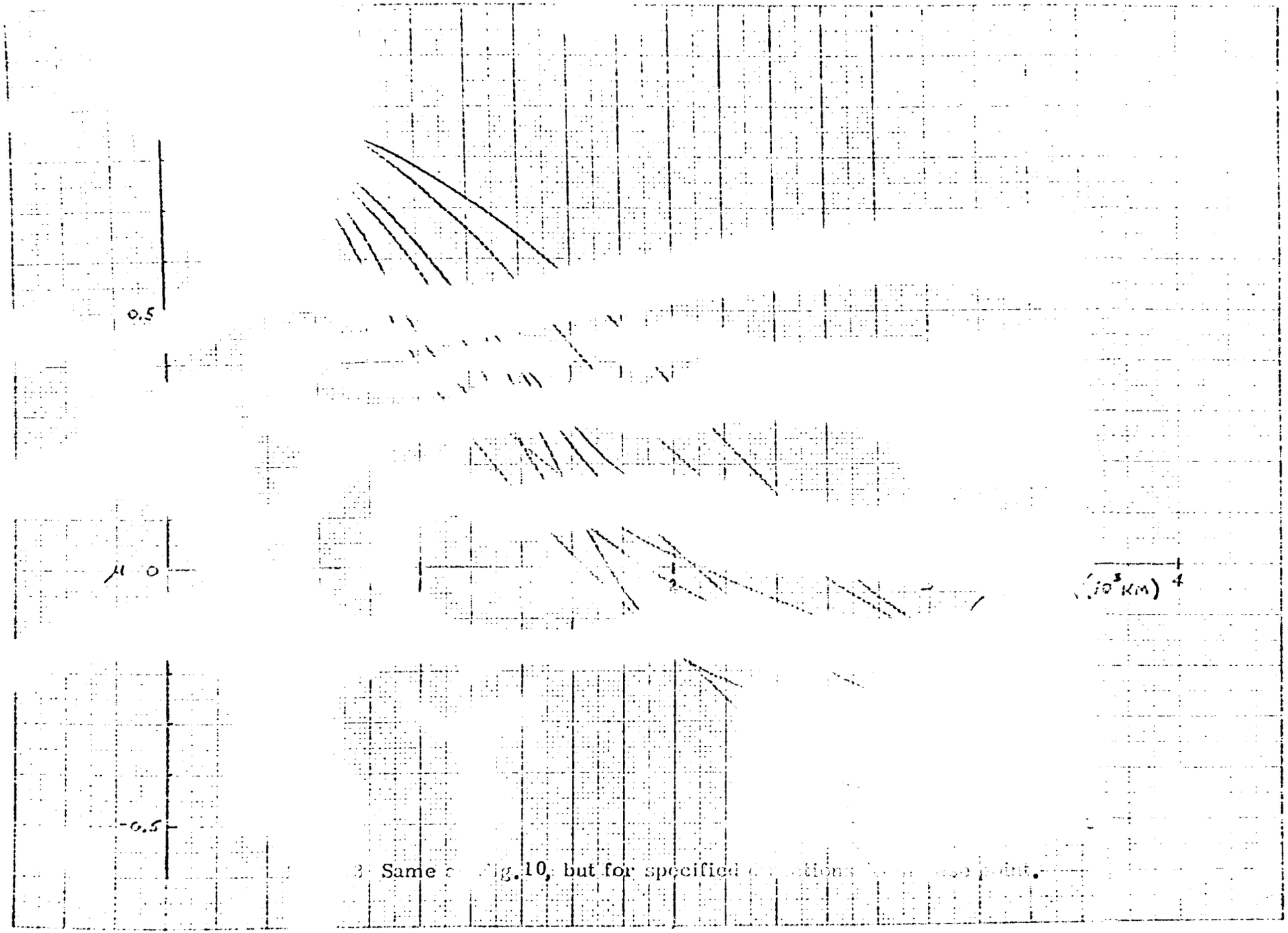


Fig. 12 Same as Fig. 9, but for specified directions from base point.



Same as Fig. 10, but for specified [illegible] point.

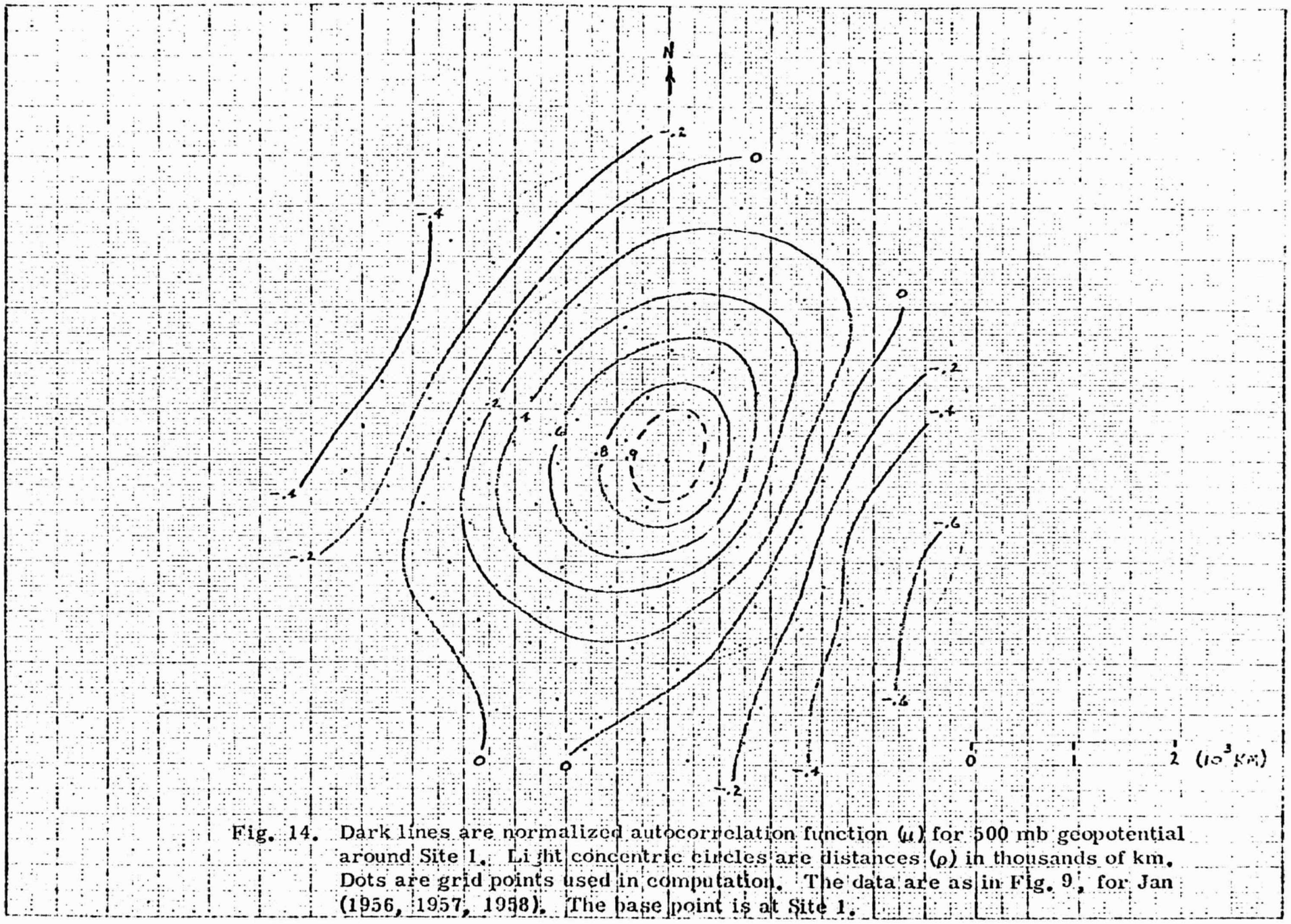


Fig. 14. Dark lines are normalized autocorrelation function (μ) for 500 mb geopotential around Site 1. Light concentric circles are distances (ρ) in thousands of km. Dots are grid points used in computation. The data are as in Fig. 9, for Jan (1956, 1957, 1958). The base point is at Site 1.

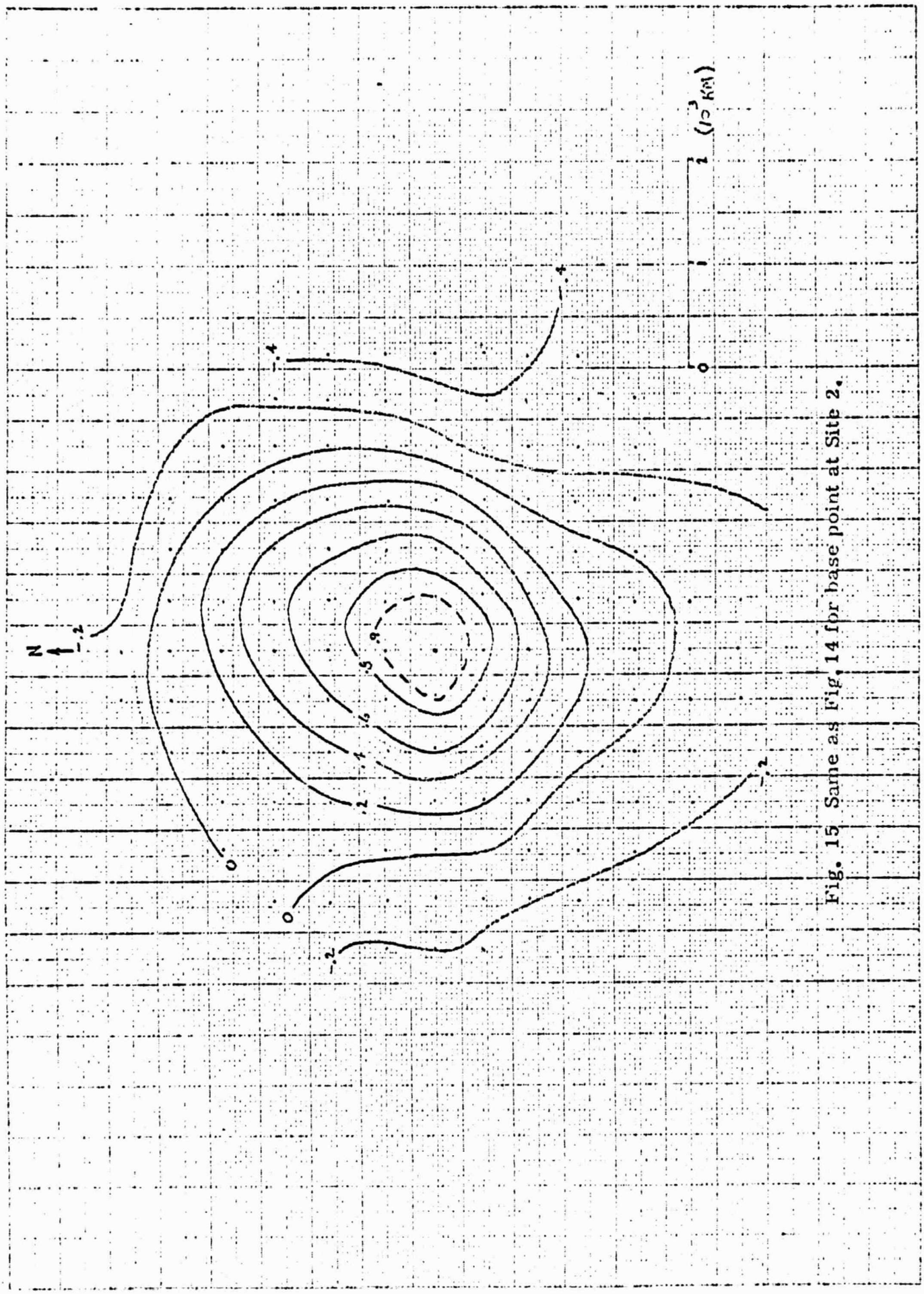


Fig. 15 Same as Fig. 14 for base point at Site 2.

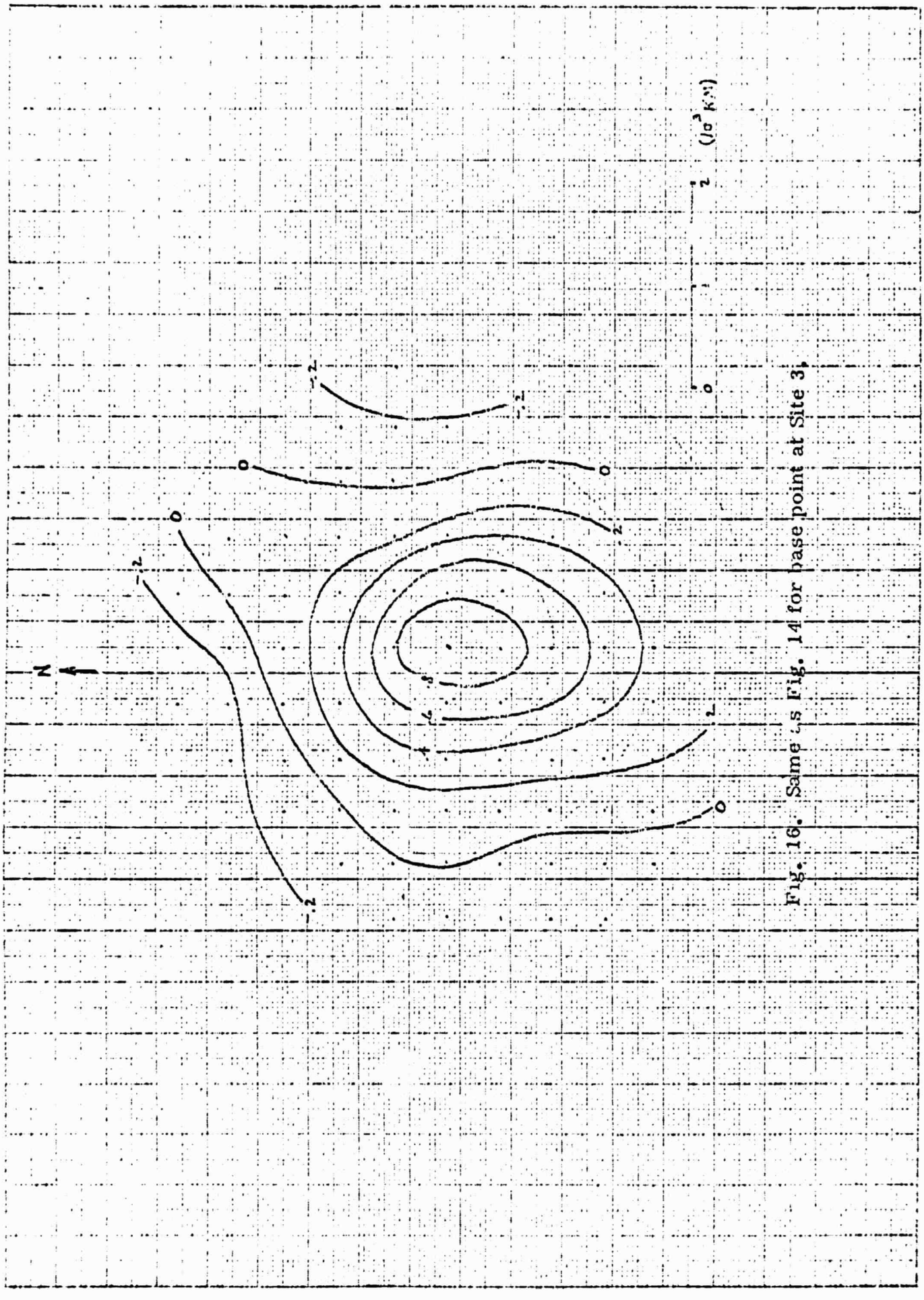


Fig. 16. Same as Fig. 14 for base point at Site 3.

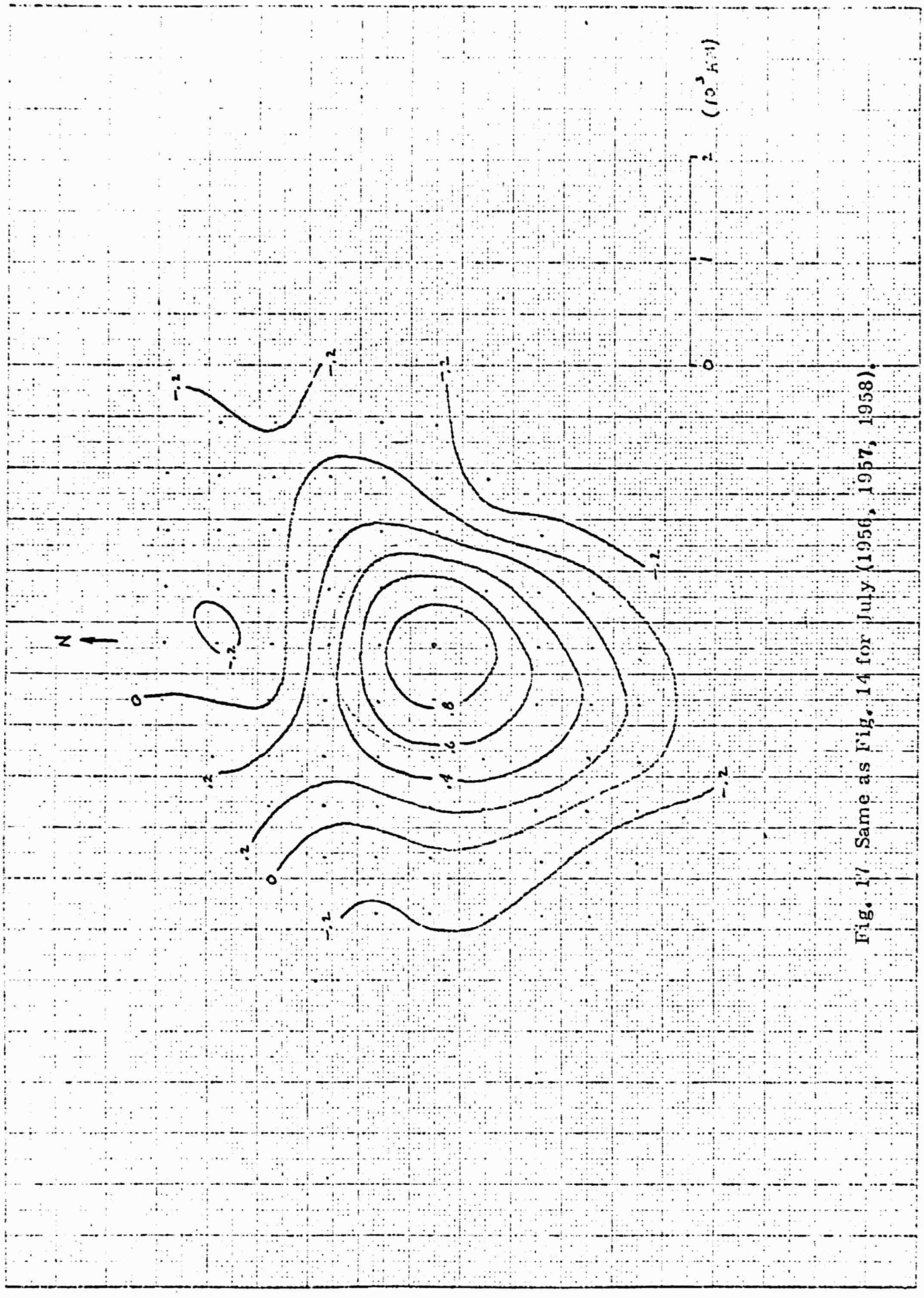


Fig. 17 Same as Fig. 14 for July (1956, 1957, 1958).

Fig. 18

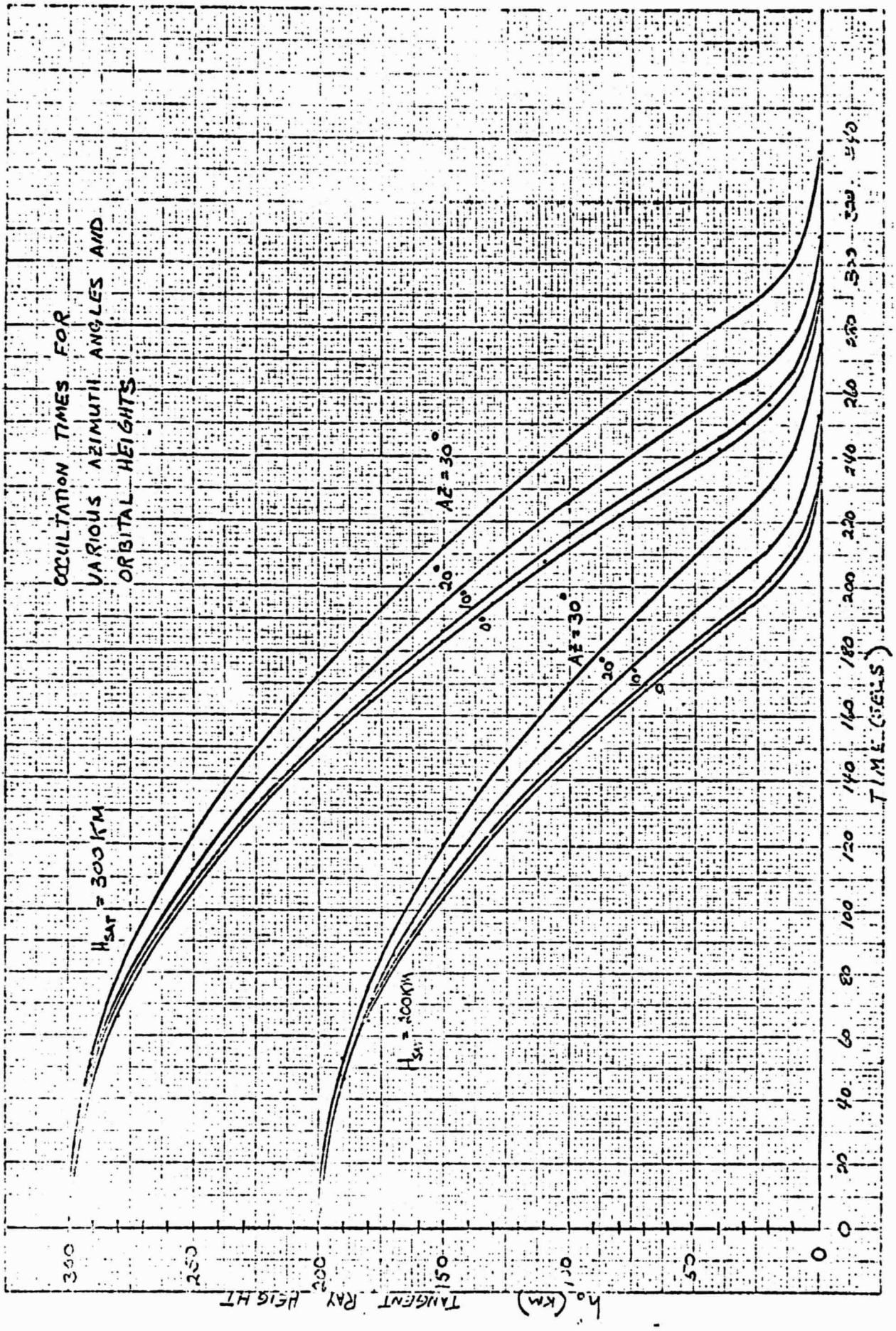


Fig. 19

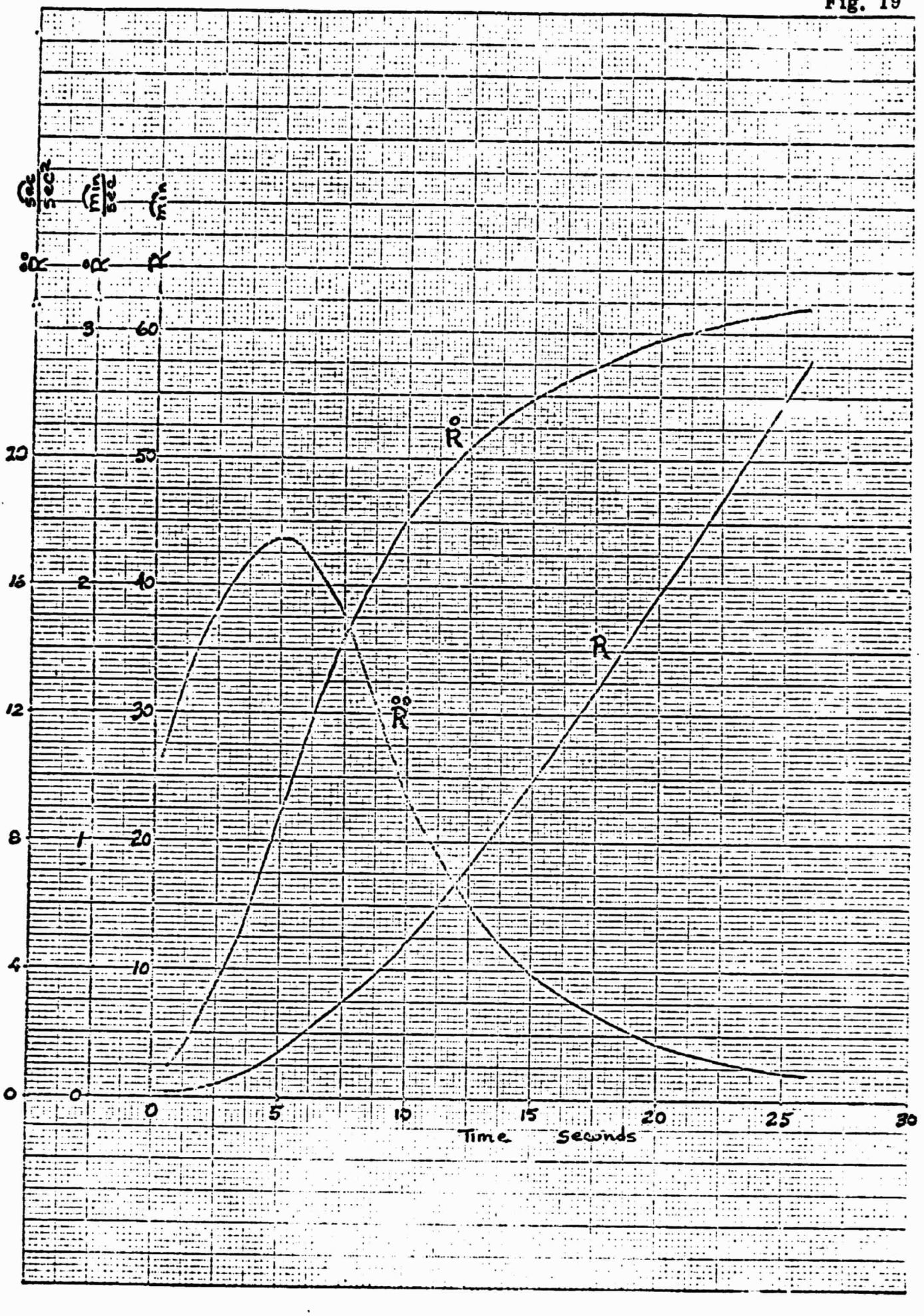
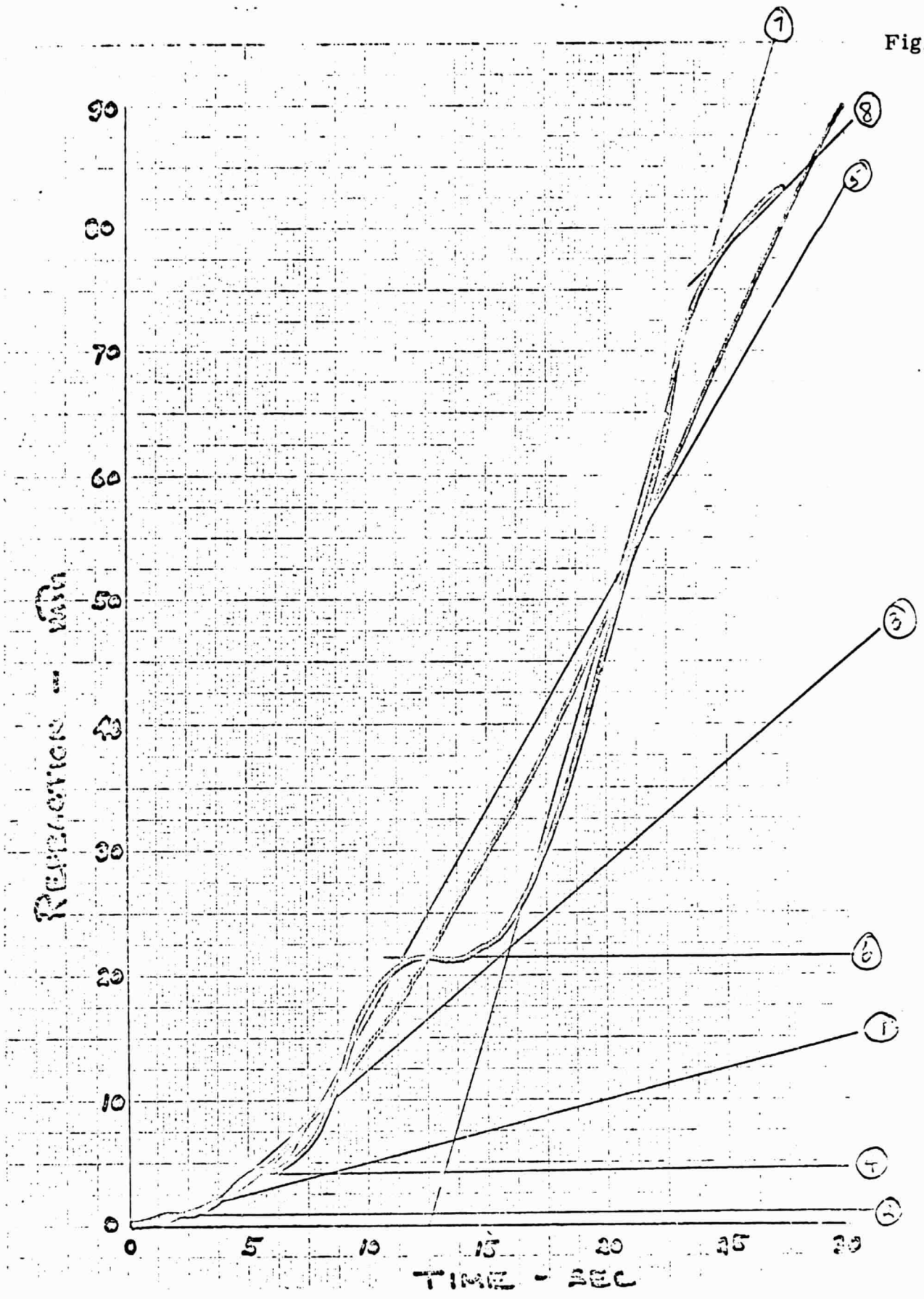


Fig. 20



Telescope

$$T = I s^2 \theta_o$$

$$\bar{T}\, T_{max} = I s^2 \bar{\theta}_o\, \theta_{o\,max}$$

$$\bar{\theta}_o = \frac{T_{max}}{I \theta_{o\,max}\, s^2}\, \bar{T}$$

$$\bar{\theta}_o = \frac{6}{s^2}\, \bar{T}$$

where $T_{max} = 60$ oz inches

$$\theta_{o\,max} = \frac{2\pi}{360} \text{ rad.}$$

$$I = 3 \text{ slug ft}^2$$

Therefore

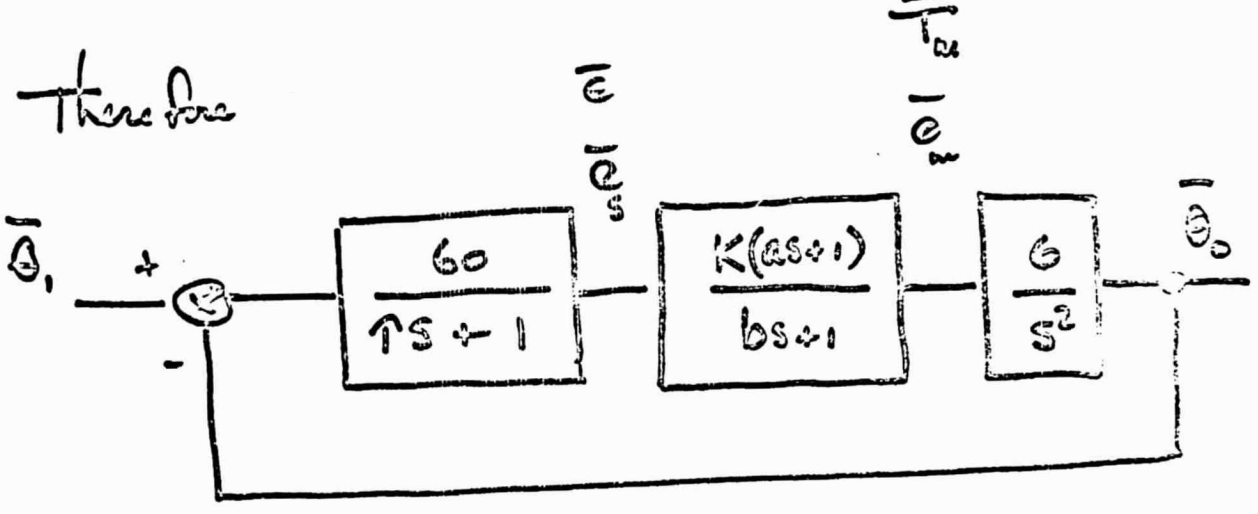


Fig. 21

Star Tracker

$\theta_{i\,max} = 60$ mm

$\epsilon_{max} = 1$ mm

Fld of View

$(\theta_i - \theta_o) K = \epsilon$

$\bar{\theta}_i \theta_{max} = \bar{\epsilon} \epsilon_{max}$

$e_s = K \epsilon$

$\bar{e}_s e_{s\,max} = K \bar{\epsilon} \epsilon_{max}$

$K = \frac{e_{s\,max}}{\epsilon_{max}}$

Volts / Angle

Network & Amplifier

$$\frac{\bar{e}_m}{\bar{e}_s} = \frac{K(as+1)}{(bs+1)}$$

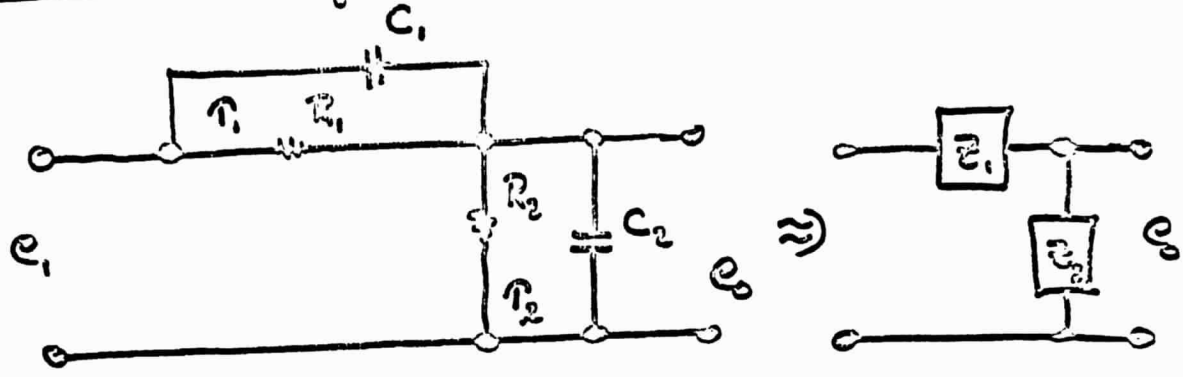
$e_m = K e_s$

$K = \frac{e_{m\,max}}{e_{s\,max}}$

$K e_m = T_m$

Fig. 22

Error Rate Network Design



$$\frac{e_0}{e_i} = \frac{Z_2}{Z_1 + Z_2} \qquad Z_1 = \frac{R_1}{\tau_1 p + 1}\ ;\ Z_2 = \frac{R_2}{\tau_2 p + 1}$$

$$= \frac{\dfrac{R_2}{\tau_2 p + 1}}{\dfrac{R_2}{\tau_2 p + 1} + \dfrac{R_1}{\tau_1 p + 1}} = \frac{R_2(\tau_1 p + 1)}{(R_2\tau_1 + R_1\tau_2)p + R_1 + R_2}$$

$$= \frac{\left(\dfrac{R_2}{R_1 + R_2}\right)(\tau_1 p + 1)}{\left(\dfrac{R_2\tau_1 + R_1\tau_2}{R_1 + R_2}\right)p + 1}$$

Choose $R_1 = .1$ meg $\qquad R_2 = .01$ meg

$C_1 = 10\,\mu\mu f \qquad C_2 = 1.0\,\mu\mu f.$

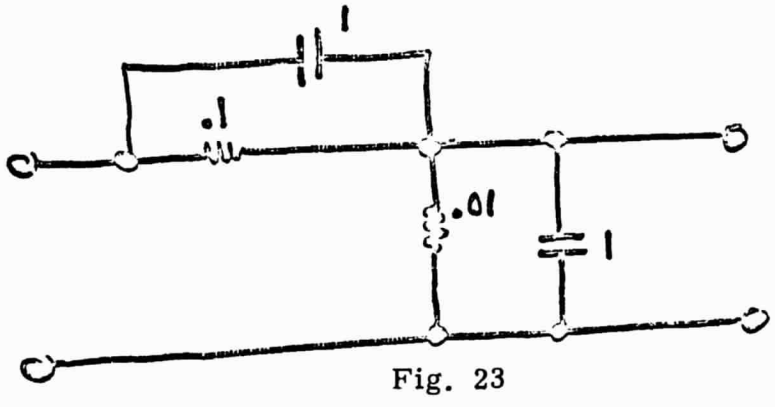
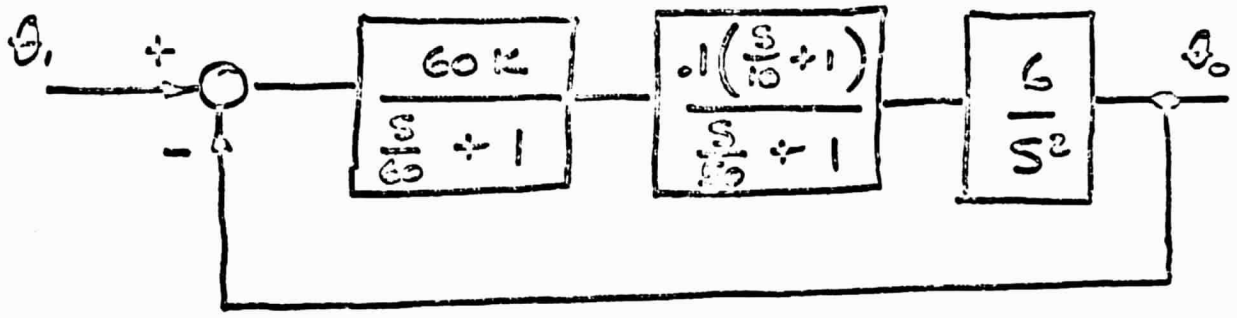
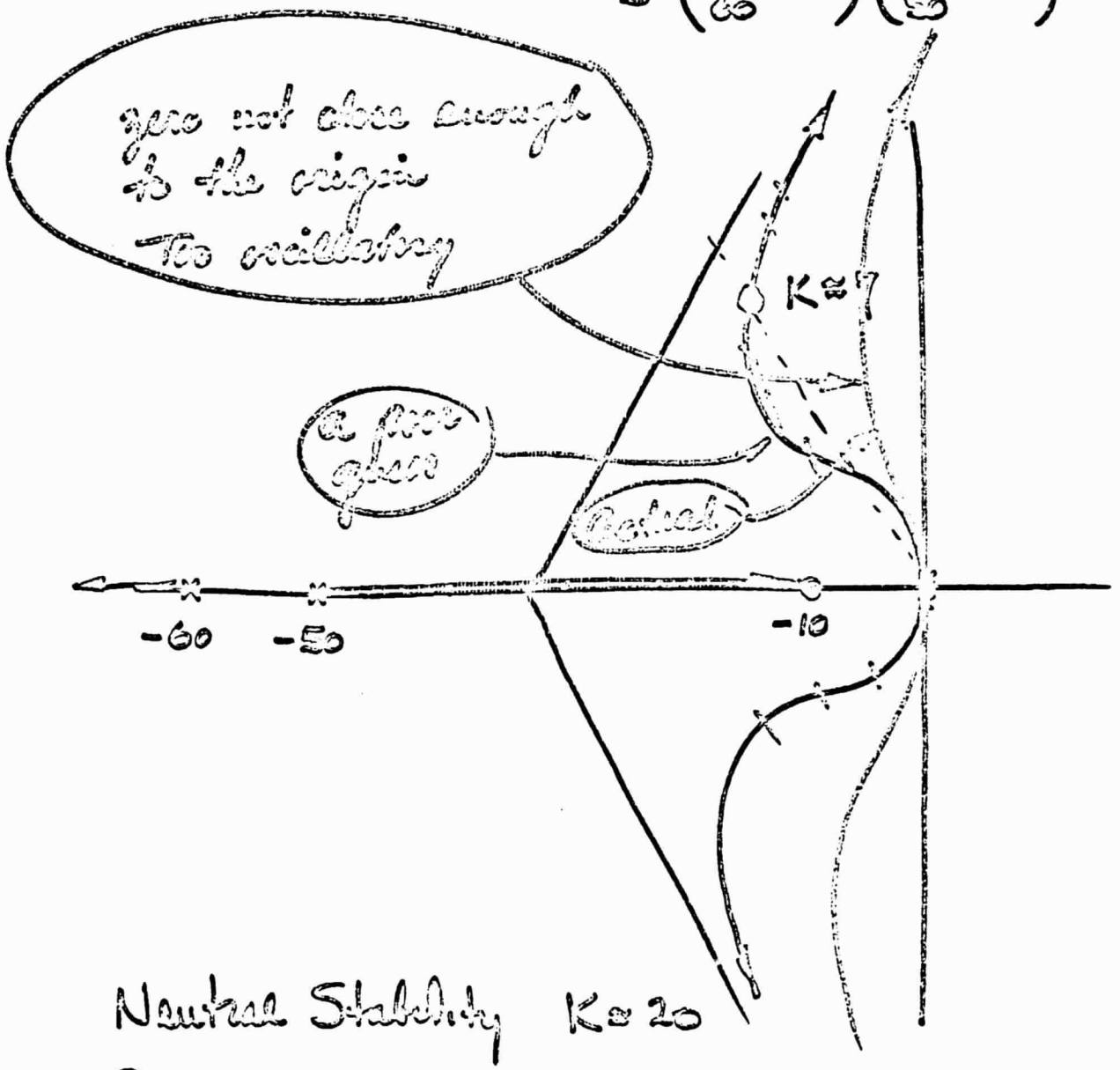


Fig. 23



$$Y = \frac{36K\left(\frac{S}{10}+1\right)}{S^2\left(\frac{S}{6}+1\right)\left(\frac{S}{5}+1\right)}$$

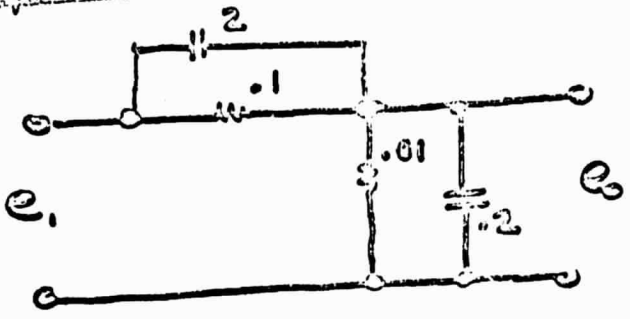


Neutral Stability K≈20

Complex poles $\zeta = \frac{1}{2}$ for K≈7

Fig. 24

Tiny Network



$$\frac{e_0}{e_1} = \frac{.09\left(\frac{s}{5}+1\right)}{\frac{s}{5}\frac{s}{6}+1}$$

$$Y = \frac{6K(5.4)\left(\frac{s}{5}+1\right)}{s^2\left(\frac{s}{5}\frac{s}{6}+1\right)\left(\frac{s}{6}+1\right)} = \frac{3600K(5.4)(s+5)}{s^2(s+50)(s+60)}$$

Fig. 25

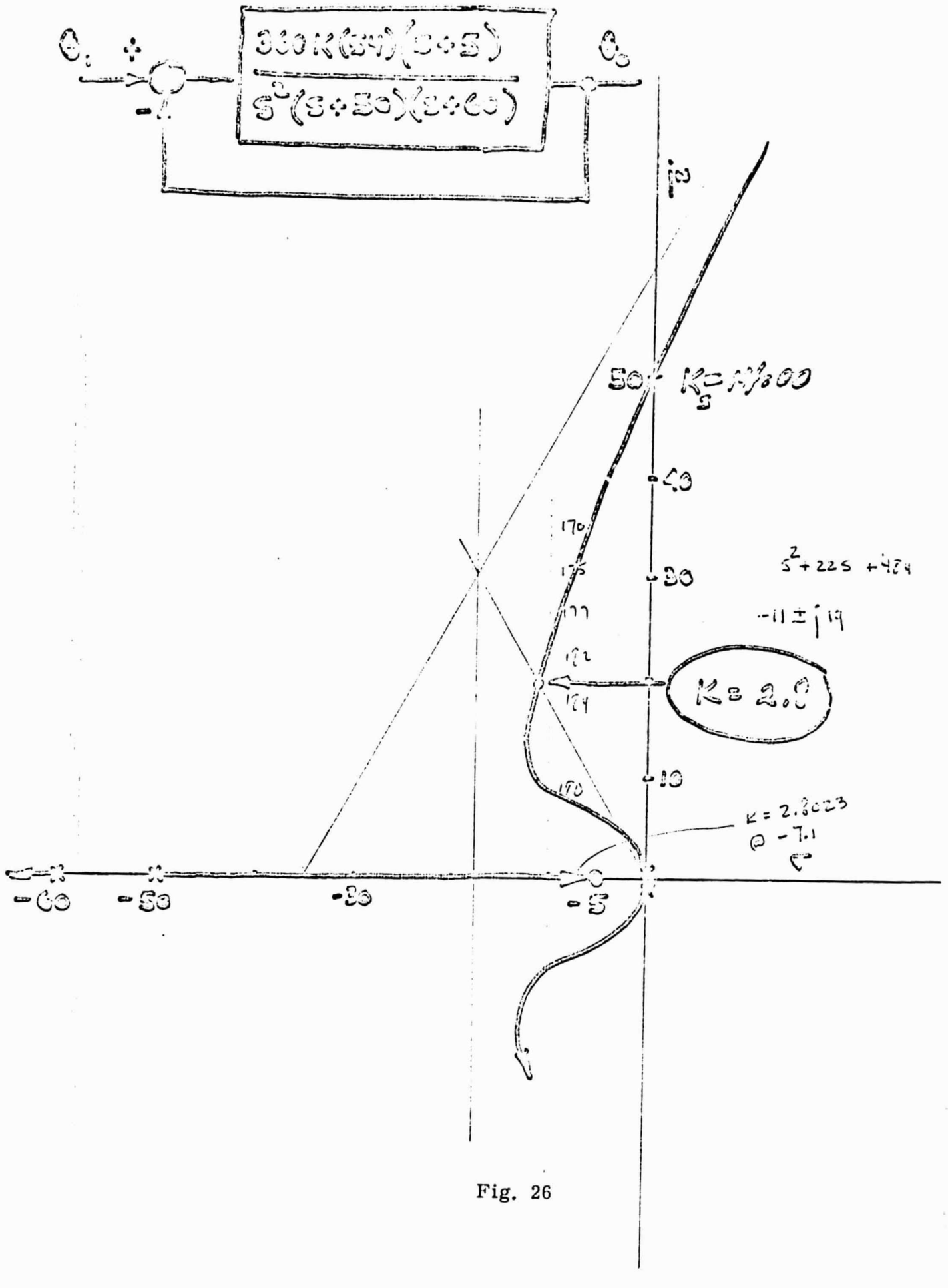
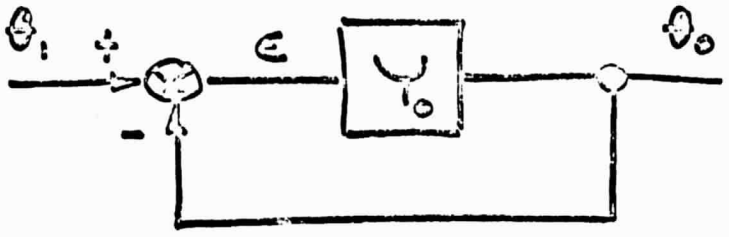

$\frac{300K(s+1)(s+3)}{s^3(s+30)(s+60)}$
θ_i
θ_o
-1
j50
50
40
30
10
$K_s = 4\%00$
$s^2 + 22s + 484$
$-11 \pm j19$
$K = 2.8023$
$\theta = -7.1°$
170
175
177
179
179
$K_s = 2.0$
-60
-50
-30
-5

Fig. 26



$$\frac{\epsilon}{\theta_1} = \frac{1}{1 + Y_0}$$

$$\epsilon(j\omega) = Z(j\omega)\,\theta_1(j\omega)$$

$$Y_0(s) = \frac{360(2.8)(54)(s+5)}{s^2(s+50)(s+60)}$$

$$Y(j\omega) = \frac{A(5+j\omega)(5-j\omega)}{[+\omega^2(+\omega^2+3300) - j\omega^3 110](5-j\omega)}$$

$$= \frac{A(25+\omega^2)}{5(\omega^4-3300\omega^2) - 110\omega^4 - j\omega^3(\omega^2-3300+550)}$$

$$= \frac{A(25+\omega^2)}{-15\omega^2(7\omega^2+1100) - j\omega^3(\omega^2-2450)}$$

$$A = 360(2.8)(54)$$
$$= 5.43 \times 10^4$$

Fig. 27

Since $\frac{C}{\theta_i} = \frac{1}{1 + Y_0}$ and

$$Y_0 = \frac{-A(25 + \omega^2)}{15\omega^2(7\omega^2 + 1000) + j\omega^3(\omega^2 - 2450)}$$

$$= \frac{-\frac{A(25+\omega^2)}{15\omega^2(7\omega^2+1000)}}{1 + j\frac{\omega(\omega^2-2450)}{15(7\omega^2+1000)}}$$

As $\omega \to \infty$ $\quad Y_0 \to \frac{K}{-j\omega^3} = j\frac{K}{\omega^3}$

$\omega \to 0$ $\quad Y_0 \to -\frac{K}{\omega^2}$

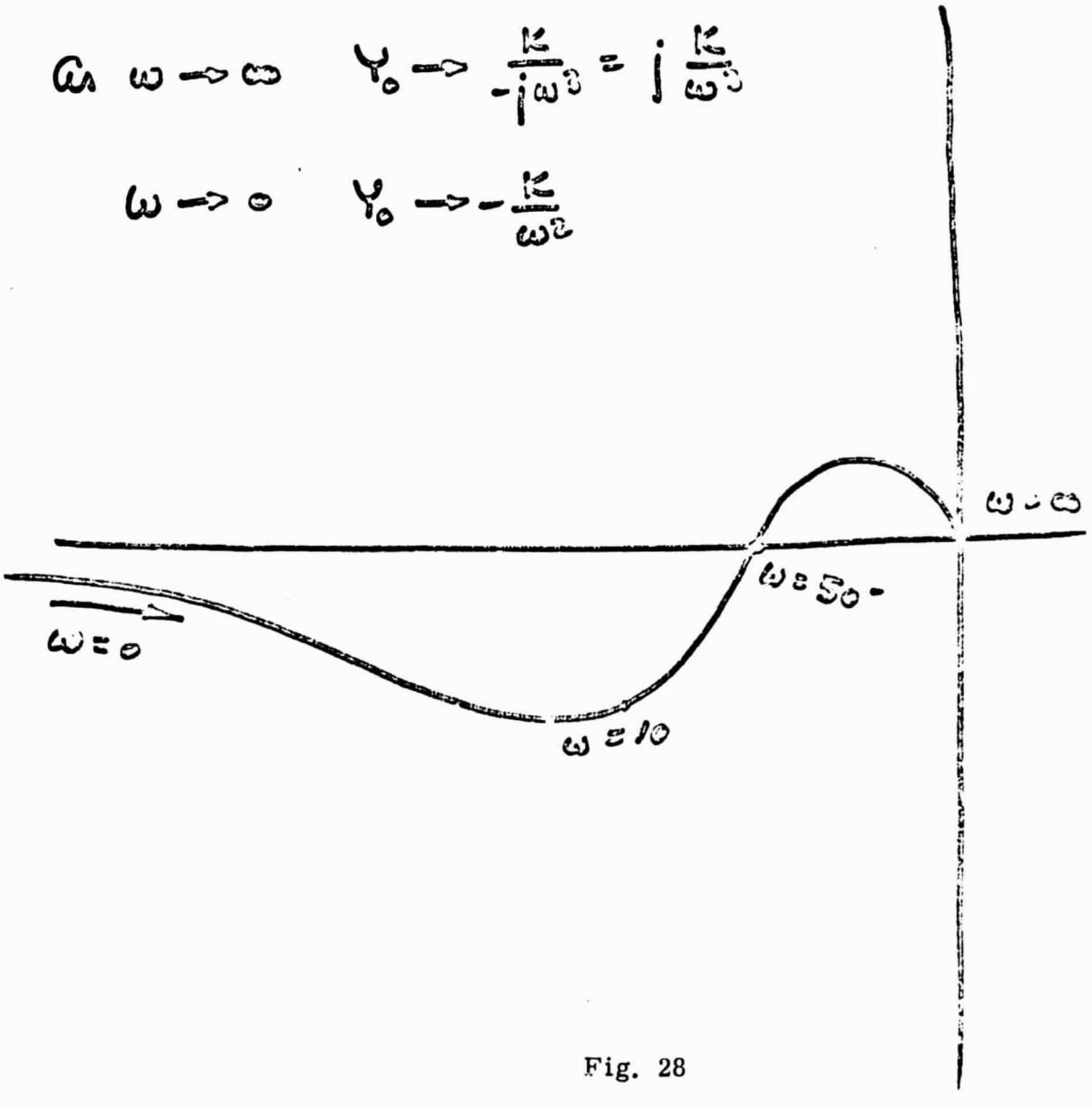


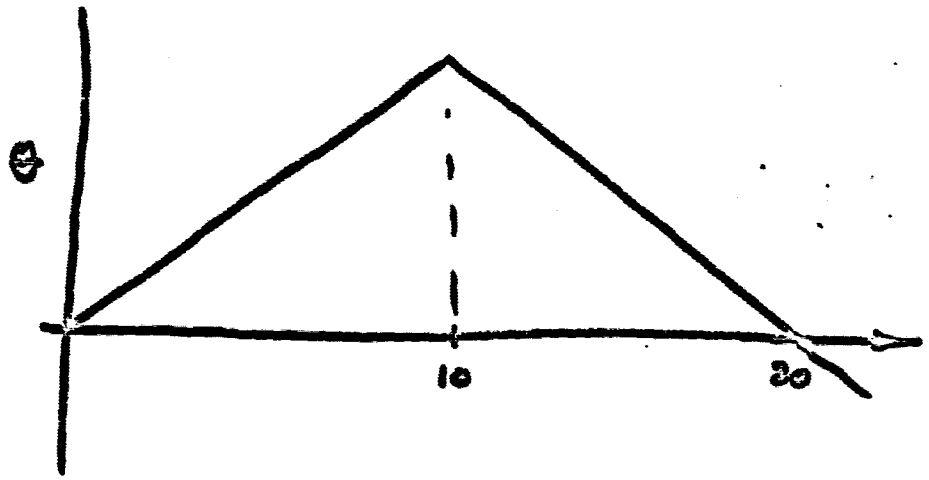
Fig. 28

$$Y = \frac{M}{1 + jy}$$

ω^2	jy	M
400	.719	1.01
225	.864	
100	.902	2.66
64	.879	
25	.688	6.1617
9	.459	12.86
1	.162	93.46
.09	.049	1×10^3
.01	.0163	9053
.0009	.0049	1.0×10^5
.0001	.00163	9.05×10^5

Fig. 29

Transient Response of Apollo Limit Cycle



$$\theta = \frac{t}{20} \qquad 0 < t \leq 10 \text{ sec}$$

$$\theta = 1 - \frac{t}{20} \qquad 10 < t < 20$$

$$\theta(s) = \frac{1}{20s^2} - e^{-10s}\frac{2}{40s^2} = \frac{1}{20s^2}\left(1 - 2e^{-10s}\right)$$

$$\epsilon(s) = \frac{\theta_1(s)}{1 + Y(s)} = \frac{s^2(s+50)(s+60)\,\theta_1(s)}{(s+7.1)(s+81)(s^2+22s+484)}$$

$$= \frac{.05\,(s+50)(s+60)}{(s+7.1)(s+81)(s^2+22s+484)}$$

$$= \frac{A}{s+7.1} + \frac{B}{s+81} + \frac{Cs+D}{s^2+22s+484}$$

$A = +0.00406$
$B = -0.0000837$
$C = -0.00398$
$D = -0.01544$

Fig. 30

Evaluation of C and D

$$As^3 + Bs^3 + Cs^3 = 0$$

$$C = -A - B$$

$$= -0.00398$$

$$484(81)A + 484(7.1)B + 7.1(81)D = 150$$

$$D = -0.01544$$

$$\frac{D}{s^2+22s+484} = \frac{D}{(s+11)^2+(19.1833)^2}$$

$$f(t) = \frac{D}{19.1833} e^{-11t} \sin(19.1833\,t)$$

$$\frac{-0.00398(s+11) + 0.02834}{(s+11)^2+(19.1833)^2}$$

$$e^{-11t}\left[+5.318 \sin \omega t - 14.328 \cos \omega t\right]$$ Ans.

$$\omega = 19.1833 \frac{\text{rad}}{\text{sec}} = 3.05 \text{ cps}$$

Fig. 31

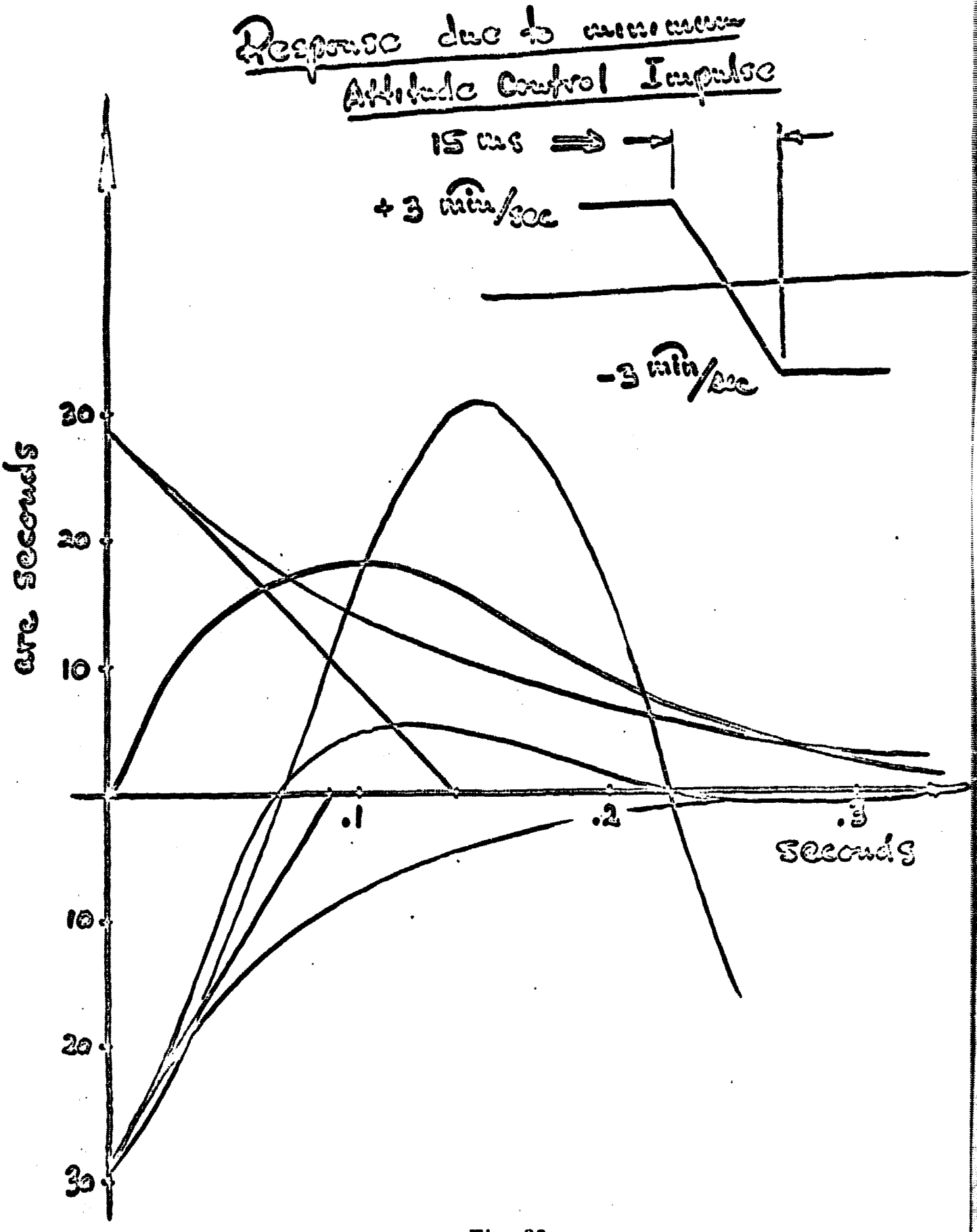

Response due to minimum
Attitude Control Impulse
15 ms
+3 min/sec
-3 min/sec
30
20
10
10
20
30
arc seconds
.1
.2
.3
seconds

Fig. 32

Specification No. S-047-1

Revision No. N/A

Release Date 1 July 1968

PRELIMINARY
CONTRACT END ITEM DETAIL SPECIFICATION
(PRIME EQUIPMENT)

PERFORMANCE/DESIGN
and
PRODUCT CONFIGURATION
REQUIREMENTS

CEI NO. NAS 9-7457 - IV.A.

STELLAR REFRACTION STAR-TRACKER
S-047 EXPERIMENT APOLLO APPLICATIONS "A"

Approved by Not for bids

Date 1 July 1968

Contract No. NAS 9-7457

Specification No. S-047-1

Release Date 1 July 1968

1. SCOPE

This part of the specification establishes the requirements for performance, design, test and qualification of one type of equipment identified as the "Stellar Refraction Star Tracker" CEI NAS 9-7457-IV.1.

2. APPLICABLE DOCUMENTS

PROJECT DOCUMENTS

University of Michigan ORA Tech Rpt 04963-3-T

University of Michigan ORA Tech Rpt 06647-1-T

DRAWINGS

H1-52001	Motor, Inland T-2170
H1-52002	Rotor shaft
H1-52003	Dummy shaft
H1-52004	Flex-pivot
H1-52005	Ring, rotor clamp
H1-52006	Field cup
H1-52007	Pivot mount
H3-52003	Atwill demodulator
H3-52004	Atwill scan generator & torque compensator
H3-52005	Tube-data scope
H3-52006	Base-data scope
H3-52007	Mount-mirror
H3-52010	Atwill scan generator
H3-52011	Horizontal & vertical raster scan generator
H3-52016	Peak light intensity hold detector
H3-52017	Focus regulator and deflection coil drivers

H3-52018	Data telescope logic card
H3-52021	Torque motor drive amplifier
H3-52022	Pre-amplifier, signal dissector
H3-52023	Inner gimbal
H3-52025	Vertical raster scan generator
H3-52026	Horizontal raster scan generator
H5-52001	Middle gimbal
H5-52002	Outer gimbal
GPI C543003439	Schematic diagram, gyroscope intergrating
GPI C162564002	Envelope drawing, gyroscope integrating

SPECIFICATIONS

MIL-E-5272 Amendment 1 "Environmental Testing, Aeronautical & Associated Equipment, General Spacification for Kearfott C182564252 "Test Instruction, Gyroscope Integrating"

STANDARDS

MIL-STD-810A "Military Standard - Environmental Test Methods for Aerospace and Ground Equipment"

MIL-STD-826A "Military Standard - Electromagnetic Interference: Test Requirements and Test Methods"

MIL-STD-143A "Military Standard - Specifications and Standards, Order of Precedence for the Selection of"

MIL-STD-129D "Military Standard - Marking for Shipment and Storage" (As changed)

BULLETINS

NASA-MSC-DS-21 Rev. A. "Meteoroid Environment - Near-Earth and Cis-Lunar"

OTHER PUBLICATIONS

NASA-MSC-D-NA-0002 "Procedures & Requirements for the Flammability and Offgassing Evaluation of Manned Spacecraft Non-Metallic Materials"

NASA-MSC-PA-D-67-13 "Apollo Spacecraft Non-Metallic Materials Requirements"

NASA-NPC-500-10 "Apollo Test Requirements"

NASA-NPC-200-1A "Quality Program Provisions for Space System Contractors"

NASA-NPC-200-3 "Inspection System Provisions for Suppliers of Space Materials, Parts, Components, and Services"

NASA-NPC-200-4A "Quality Requirements for Hand Soldering of Electrical Connections"

NASA-NPC-250-1 "Reliability Program Provisions for Space System Contractors"

NASA-NPC-500-1 "Apollo Configuration Management Manual"

NASA-MSC-Supplement #1 to NPC-500-1 Revision B

3. REQUIREMENTS

3.1.1 Functional Characteristics

The subject equiment must:

a) Be attached to rigid spacecraft structure in a manner and position known to the astronaut and subject to monitor by the astronaut on remote indicating instrument in the command module.

b) Have functional telescopic optics capable of viewing a field 1^{o} by 1^{o} (square) or 1^{o} diametrically (circular)

c) Have associated sensing and modulation electronics capable of detecting the most intense optical signal in the telescopic field-of-view

d) Have gimbals between the rigid telescopic optical system and the spacecraft allowing $2^{o} \pm 0.1^{o}$ relative motion in any axis

e) Have a suitable detection and demodulation system to detect the vector position of the most intense visual signal from the center of the optical field-of-view, and the capability of recording this vector position by independent measurement at least once per 0.1 second. The vector must be recorded with an overall error in spherical coordinates not to exceed two seconds of arc RMS. This signal will be called the "off-axis error signal "

f) Have suitable feedback electronic system and a suitable gimbal torque system such that the off-axis error signal shall tend toward zero at all times while in operation, under conditions of spacecraft motion not to exceed 2 arc-minutes per second plus motion of the celestial source not to exceed 2 arc-minutes per second

g) Have a two-axis gyroscopic system rigidly attached to the telescope frame which detects motion of 0.1 arc second or more, providing that:

1) Motion of the telescope has not exceeded 1^{o} per second in any axis for 2.5 minutes preceding measureme
2) Motion of the telescope does not exceed 3 arc-minutes per second during measurement

The gyroscopic system must be capable of being caged and uncaged and must be operable at any acceleration less than 0.1g while uncaged

h) Have a gyroscope system (g) above) which records the motion in each axis to the precision stated at least once per 0.1 second

i) Have the ability to record the off-axis error signal as in c) above whenever the maximum intensity of optical signal available at the telescope entrance exceeds that of a 4.5 visual magnitude stellar source. Within two seconds of time after developing the initial off-axis error signal (star acquisition) the system must be operable whenever the signal exceeds in intensity that of a 9.5 visual magnitude stellar source

j) Have the capability of protecting the optical surfaces from space contamination as provided by future criteria at all times while not in operation

k) Have optical systems which provide the signals as required above whenever the sun is more than 18° below the sensible horizon

l) Have a suitable control system actuated by the astronaut so that, realignment with the spacecraft, optical contamination protection, and electrical power turn-off can be commanded by the astronaut and completed within 2.0 seconds after command

3.1.2 Operability

The equipment shall be operable over two thousand sequences each lasting at least 5 minutes and shall have a useful life of not less than 500 hours.

All other reliability, maintainability, and environmental requirements shall be identical to those specified for the Apollo spacecraft in the referenced publications above.

No special requirements exist for the equipment, other than those listed.

3.2.2 Component Identification

3.2.2.1 Government-Furnished Property List

None

3.2.2.2 Engineering Critical Components List

a) ITT F 4012 S-20 Phototube (2 ea)
b) Kearfott C172564002 Gyro (or equivalent) (2 ea)
c) Optical elements, Celestron 10 or equivalent
d) Inland motor, torque, T-2170 (2 ea)
e) Bendix Flex-Pivot 5010-600 (4 ea)

3.2.2.3 Logistics Critical Components List

Items 3.2.2.2 a) and b)

3.3 Design and Construction

3.3.1 The general design is exemplified by the comprehensive photographs attached.

The performance requirements listed above will be met by equipment fabricated in accord with the following specified drawings:

U-M H1-52001 thru 52007
U-M H3-52003 thru 52007
U-M H3-52010, 52011
U-M H3-52016, 52017, 52018
U-M H3-52021, 52022, 52023
U-M H3-52025, 52026
U-M H5-52001, 52002
ITT F 4012 S-20 and
Inland T-2170, provided that a gyroscope system be available meeting the following performance specification:

a) Gyro transfer function

The gyro open loop transfer function shall be 108.5 millivolts (mv) root mean square (RMS) ±15 percent output per milliradians displacement about the input axis when the signal generator excitation, and spin motor excitation are held at the nominal value specified and the gyro is at operating temperature.

b) Output axis freedom

The gimbal freedom about the output axis shall be mechanically limited to 3.6 ± 0.25 degrees in both directions from signal generator null position.

c) Characteristic time

The characteristic time as determined by dividing the gimbal moment of inertia about the output axis by the damping coefficient shall be 6.4 milliseconds ± 15 percent at the operating temperature.

d) Angular momentum

The gyroscope, integrating shall be designed to have a nominal angular momentum of 227,000 gram (GM) centimeter (CM) squared per second (GM CM^2/sec) at synchronous speed of 24,000 revolutions per minute (RPM).

e) Output axis inertia

The gimbal output axis inertia shall be approximately 117 grams centimeter squared (GM CM^2).

f) Open loop gain

The open loop gain shall be 12.4 ± 10 percent at operating temperature.

g) Operating temperature

The gyroscope operating temperature shall be 165 ± 5 degrees fahrenheit (F).

h) Signal generator null

With the gyro at operating temperature and standard excitation applied to the spin motor, signal primary and operating heater, the null or minimum signal secondary voltage shall not exceed 1.0 MV RMS.

i) Warmup time

The time required for the gyroscope to reach operating temperature from 70°F. as indicated by the sensor resistance shall be approximately 4 minutes.

j) Rate mode output signal noise

The maximum value of noise measured in the output signal of a gyro operated in a rate mode shall not exceed an equivalent peak input rate of 8 degrees per hour when measured under the following conditions.

Amplifier-gyro constant: closed loop velocity error coefficient, $(KV \frac{1}{SEC}) = 80 \pm 5\%$

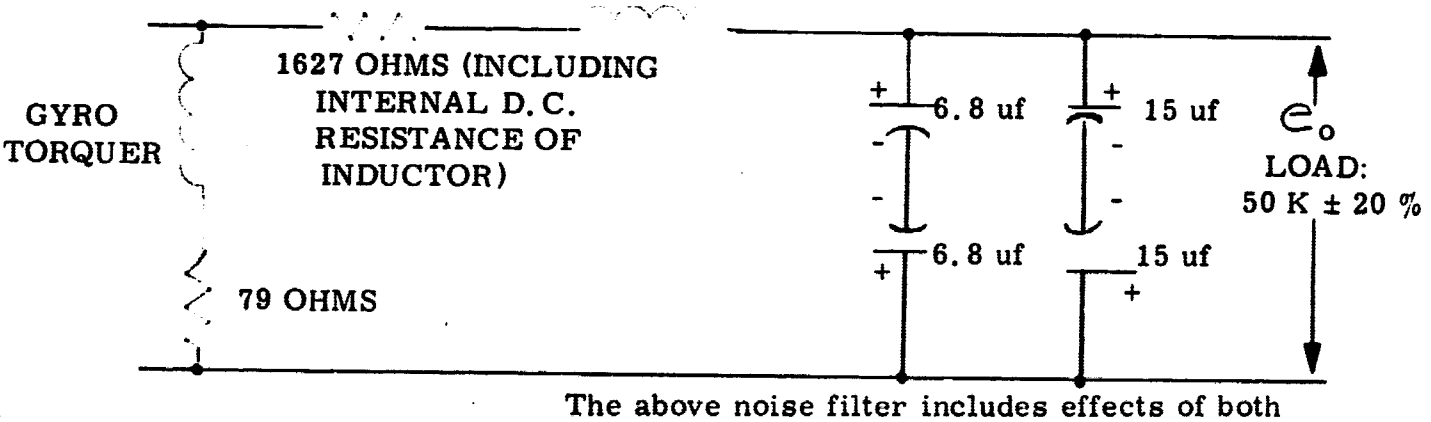
Loop damping constant: 0.7 ± 0.1 of critical

Loop natural frequency: 112.5 RAD/SEC ± 20%

Frequency response of measuring equipment 60 CPS minimum

A filter with the configuration shown below shall be inserted between the gyro output signal and the instrumentation

10 H



The above noise filter includes effects of both mechanical and electrical disturbance phenomena directly attributable to the gyro only in normal closed loop operation.

k) Acceleration insensitive drift rate

The maximum value of acceleration insensitive drift rate with the gyro at null and with no external compensation applied shall be 2°/HR.

l) Acceleration insensitive drift rate shift

The maximum change in acceleration insensitive drift rate, runup to runup, and with the gyro cooled to 70°F. for 16 hours between operating periods shall be $\pm 0.5^{\circ}$/HR. from the initial trimmed value for 3 runs.

m) Acceleration sensitive drift rate (mass unbalance drift rate)

The maximum acceleration sensitive drift rate under any condition of storage or operating environment shall be 1.0°/HR/G along the input axis (IA) and spin reference axis (SRA).

n) Acceleration sensitive drift rate shift

The maximum change in acceleration sensitive drift rate shift, runup to runup, with the gyro cooled to 70°F. for 16 hours between operating periods shall be 0.5°/HR/G from the initial value for 3 runs.

o) Random drift rate

The computed random drift (1 sigma value) for any operating position of the gyro for one-half hour shall not exceed 0.05°/HR.

p) Anisoelastic drift rate

The G^2 component of drift as computed from total drift rate data obtained with applied vibration over the frequency range of 30 to 1500 cps shall not exceed 0.02°/HR/G^2 peak; over the frequency range of 30 to 2000 cps shall not exceed 0.05°/HR/G^2 peak, except for isolated narrow frequency bands of less than 5 cycles.

q) Maximum torquing rate

The gyro shall be capable of a torquing rate equivalent to or exceeding an angular velocity about the input axis of 4.5°/sec.

r) Spin motor characteristics

The gyro spin motor shall be a synchronous, hysteresis type.

Excitation voltages: The spin motor excitation voltage shall be 26 ± 0.3 volts (V) RMS, 400 ± 0.04 cps, three phase sinewave.

Spin motor power: Starting power shall be 4.5 watts (w) maximum and running power at synchronous speed shall be 3.5 watts (w) maximum.

Spin motor current: Starting current shall be 0.154 amps maximum and running current at synchronous speed shall be 0.134 amps max.

Motor rundown time repeatability: The wheel rundown time, as measured by the elapsed time required for the back EMF to change from 20 cps to 0 cps shall not deviate by more than ± 15 seconds from the value recorded at gyro acceptance. The wheel rundown time shall be determined at gyro operating temperature, after the spin motor has been running for a minimum period of one hour.

s) Signal generator

The signal generator shall be an air core differential transformer.

Excitation: The excitation voltage on the primary winding shall be 13 ± 0.26 volts (v) RMS, 800 ± 0.08 cps, single (1) phase. The 400 cps motor supply and the 800 cps signal generator supply shall be phase locked.

Sensitivity: The sensitivity of the signal generator shall be 8.75 ± 0.9 MV per MR gimbal displacement with excitation at nominal.

Linearity: The linearity of the signal generator shall be ± 1 percent of full scale reading for gimbal travel up to ± 3.6 degrees.

Primary impedance: The primary impedance shall be 22.5 + J77 ohms ± 10 percent at 800 cps and 70°F.

Secondary impedance: The secondary impedance shall be 46 + J7ohms ± 10 percent at 800 cps and 70°F.

Phase angle: The phase angle of the signal generator primary voltage shall be 11.0 ± 3 degrees when operating into an 5k ohm load minimum, when the gyro is at 70°F.

Signal generator input current: The input current to the signal generator primary shall be 0.210 amps maximum.

t) Torque generator

The torque generator shall be a permanent magnet D'arsonval type.

Torquer scale factor: The torque generator scale factor at signal generator null shall be 134 ± 13 degrees/HR/MA DC.

Torquer linearity: The torquer linearity at gimbal null shall be ± 0.05% for rates from 0 to 100°/HR. This linearity error is the maximum deviation from the best straight line.

Torquer resistance: The torquer control field DC resistance shall be 38 ohms ± 10 percent at 70°F.

Control field time constant: The control field time constant shall be 55 microseconds ± 10 percent at 70°F.

Torque generator maximum current: The maximum current applied to the torquer generator secondary shall be limited to 250 milliamps.

u) Temperature sensing element

The temperature sensing element shall be adjusted to have a DC resistance of 780 ohms at operating temperature.

v) Heater windings

Control heater: (Operating heater)

Resistance: The control heater DC resistance shall be 31.4 ± 3.1 ohms at 70°F.

Power: The maximum control heater power shall be 30 watts when excited with 28 volts DC.

Warmup heater:

Resistance: The warmup heater DC resistance shall be 132 ± 13 ohms at 70°F.

Power: The maximum warmup heater power shall be 112 watts when excited with 115 volts, 60 cps, single phase.

3.3.2. Selection of specfications and standards shall be in accord with MIL-STD-143A.

3.3.3 Materials are specified in the materials and parts specifications. In those instances where substitution or qualification is required the materials shall be suitable, best commercial quality, non-toxic, light weight and non-flammable when possible.

3.3.4. All parts not covered by appropriate drawings attached hereto, are standard commerical parts. In most cases the parts are available from the Apollo Qualified Parts List. For the parts not so covered, qualification or redesign as per the Materials and Parts Specification shall be made.

3.3.5. Materials susceptible to humidity degradation or which are fungus nutrients shall not be used. If a substitute for a fungus nutrient material is not commerically available, the material shall be treated with a fungicide retaining efficacy for five years. The fungicide will require qualification and testinf for offgassing properties.

3.3.6. The corrosion of metal parts shall be precluded by appropriate plating or anodizing. The corrosion which might be caused by dissimilar metallic junclions has been prevented by proper design with the exception of fasteners which have been for strength and weight considerations been exclusively restricted to stainless steel. Protective coating of the fastener-part interfaces is required and inspection and storage specifications must reflect this requirement in their provisions.

3.3.7. No special provisions for interchangeability and replaceability have been made.

3.3.8. Workmanship reflecting evidence of excellent shop practice is required throughout. Correct and uniform torquing is required on all parts and there shall be no evidence of scars, burrs, or scratches resulting from assembly operations.

3.3.9. Electromagnetic interference shall be a subject of integration test only. Integration specifications have not been issued. Testing provisions of MIL-STD-826A are fully applicable.

3.3.10. Identification and marking shall follow provisions of MIL-STD-129D and changes thereto, and as supplemented by MSC directives.

4. QUALITY ASSURANCE PROVISIONS

4.1 Test/Verification

4.1.1 Engineering test and evaluation shall be performed in compliance with University of Michigan systems engineering group standards and conducted in the University facilities.

4.1.2 Qualification testing shall be conducted at the appropriate local manufacturers test facilities and in compliance with the qualification test standards established by The University quality and reliability program groups.

4.1.3 Engineering critical component qualification shall be conducted as follows:

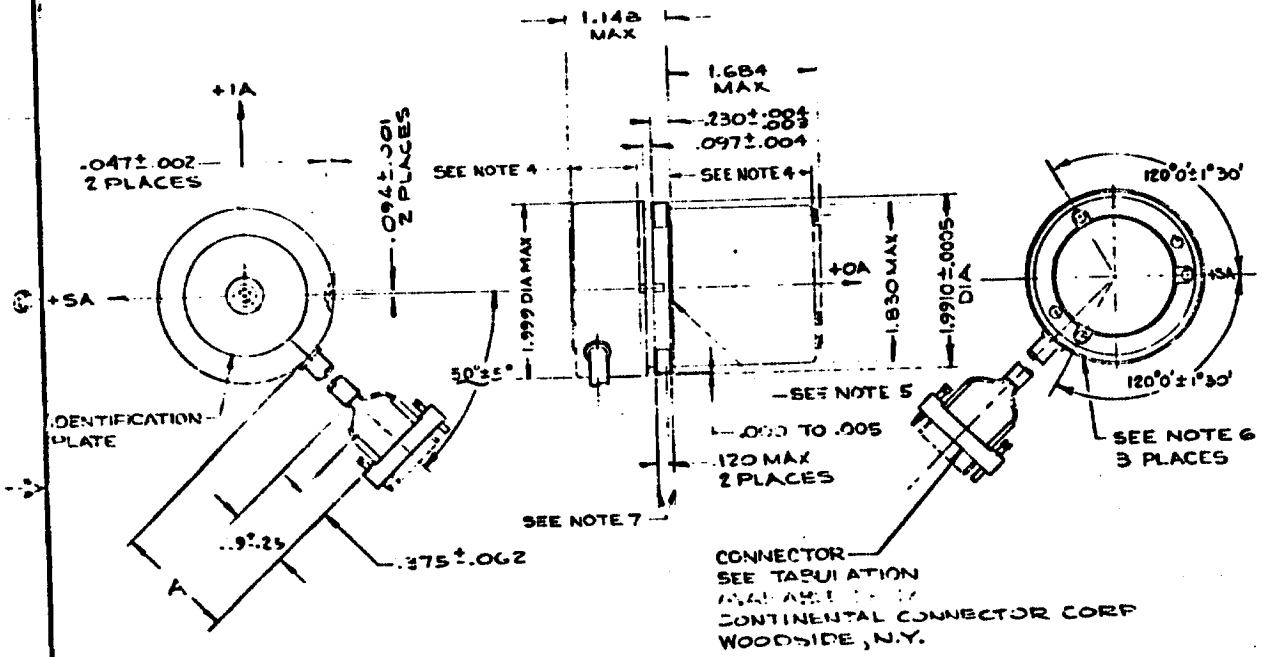
Item:
a) Manufacturer's plant
b) Manufacturer's plant
c) University of Michigan or local facility
d) University of Michigan
e) University of Michigan

4.2 Integrated Test Requirement

Not applicable

5. Notes

None



REVISIONS				
LTR	ZONE	DESCRIPTION	DATE	APPROVED
		RELEASE		
		C.O. 4050-TB REVISED LOCATION OF 50°±5°	7-1-64	
		C.O. 4050-TJ ADDED 120°±1°30' (2 PLACES); +0A; SEE NOTE 6; 3 PLACES; REVISED PICTURE TO SHOW INSULATING PADS;	8-3-65	
	3B	ADDED SEE NOTE 6; REVISED TAB BOX		
	4C	1.9910±.0005 DIA WAS 1.999 ±.001 DIA		
	4A	ADDED NOTES 6 & 7		
	4B	ADDED .160 MAX; .140 MAX		
	4C	ADDED .200 DIA MAX; REVISED PICTURE OF CONNECTOR		
D		C.O. 4050-TZ	9-9-65	
	4B	ADDED .120 +.060 -.000; .10;		
	4C	REVISED PICTURE OF CONNECTOR		
E		RN20372 DELETED .672 MAX, .200 MAX, .28 MAX, .10, .160 MAX	6-14-66	
	4C	.120 +.060 -.000, .140 MAX, ADDED		
	3C	.375±.062, .69±.25 REVISED		
	2C	PICTURE		

NOTES:

1. SCHEMATIC DIAGRAM: SEE TABULATION
2. ASSEMBLY: SEE TABULATION
3. FINISH AND MARKING IN ACCORDANCE WITH FED-STD-595 SPEC: SEE TABULATION
4. BLACK OXIDE SURFACES TO HAVE A MINIMUM EMISSIVITY OF .6 AT 135°F. EMISSIVITY VALUE IS ESTABLISHED BY DESIGN. BLACK OXIDE IS NOT REQUIRED ON THE GYRO MOUNTING FLANGE.
5. GYROSCOPE THERMAL INSULATOR
6. GYROSCOPE INSULATING PADS
7. INSULATING PADS NOT TO EXTEND BEYOND THESE SURFACES

PART NO.	ASSEMBLY NO.	PERFORMANCE NO.			
C1625640002 C1625640001	C7025640002 C7025640001	C1725640002 C1725640001	4.000±.250 4.750±.250	MM20-22PGDSL MM20-22PGDS	C343003431 C343003439
			A	CONNECTOR	SCHEMATIC

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DIMENSIONS
DECIMAL: 2 PLACE ± .03; 3 PLACE ± .010; 4 PLACE ± .0005
ANGULAR ±
FRACTIONAL ±
MATERIAL
FINISH

DRAWING GRADE (E)
ER 7-21-64
CHK
ENGR 7-21-64
APPD

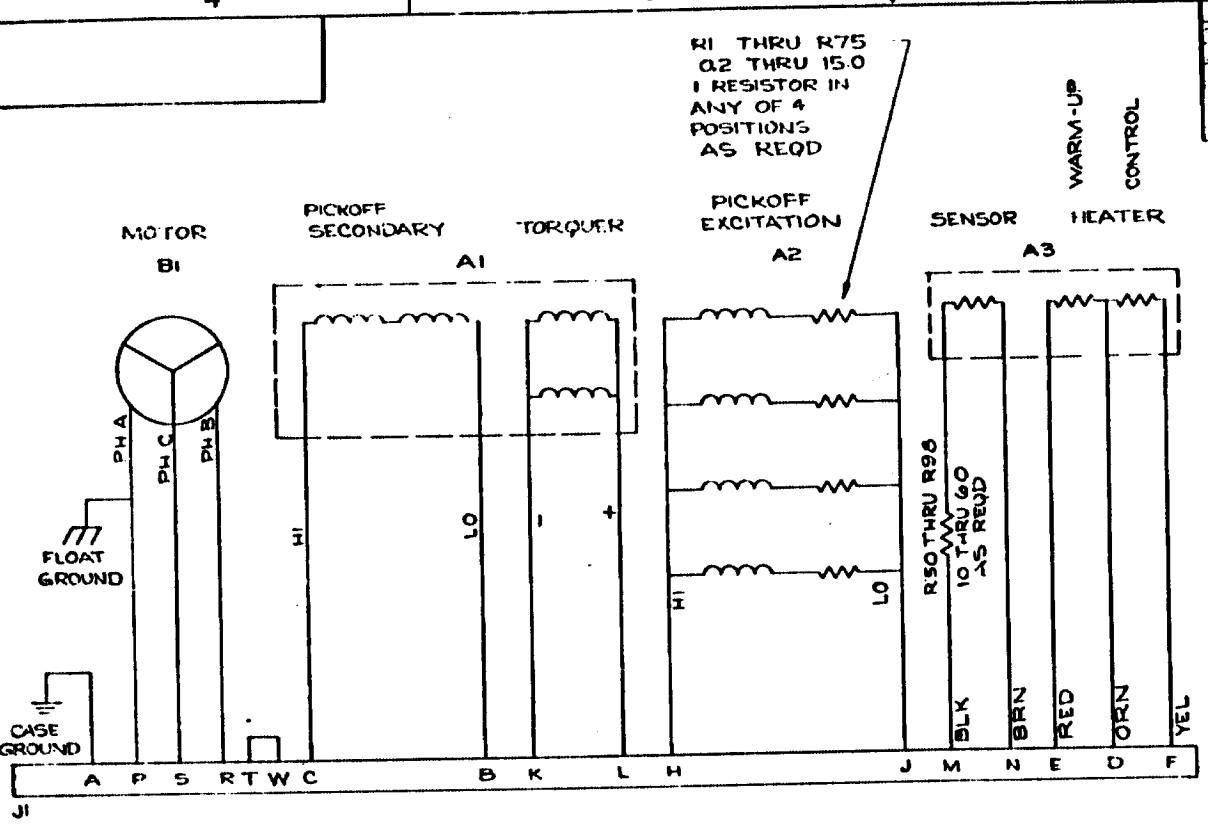
GENERAL PRECISION, INC
AEROSPACE GROUP
LITTLE FALLS, NEW JERSEY

ENVELOPE DRAWING GYROSCOPE, INTEGRATING

CODE IDENT NO	SIZE	
88818	C	THRU C162564001 C162564002

SCALE 1/1 SHEET

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
A		RELEASE		
B	C2	KN 22675 R50 THRU ---- AS REQD NAS R76 THRU R93, 16 THRU 50 AS REQD		



NOTES

1 ASSEMBLY C10256400I
2 COMPONENTS LIST C543051562
3 UNLESS OTHERWISE SPECIFIED RESISTANCE VALUES ARE IN OHMS

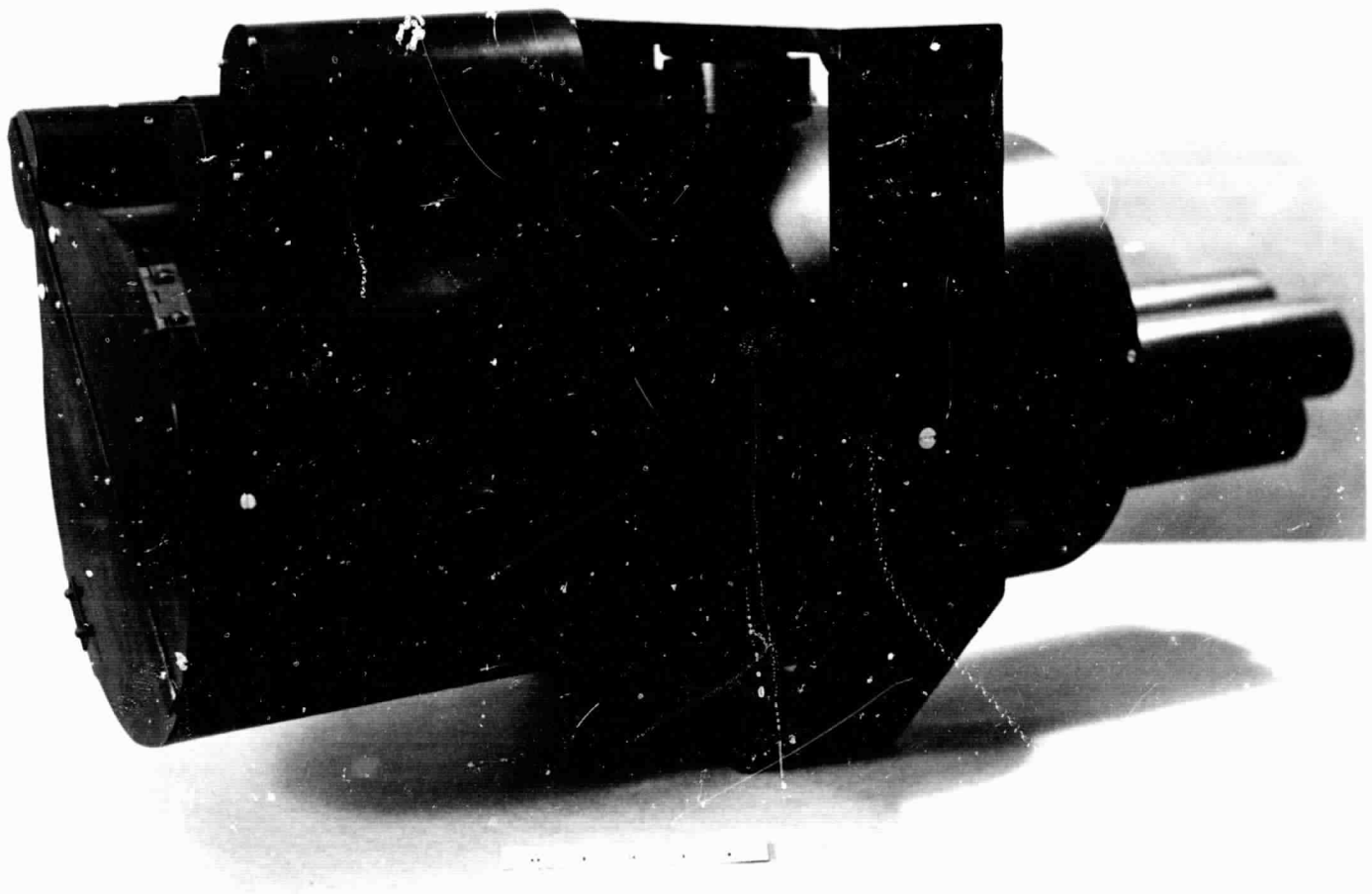
UNLESS OTHERWISE SPECIFIED			
DIMENSIONS ARE IN INCHES TOLERANCES ON DIMENSIONS			
DECIMAL	ANGULAR	FRACTIONAL	
2 PLACE ± .03	±	±	
3 PLACE ± .010			
4 PLACE ± .0005			
MATERIAL			
FINISH			

DRAWING GRADE (E)
DR
CHK
ENGR
APPD

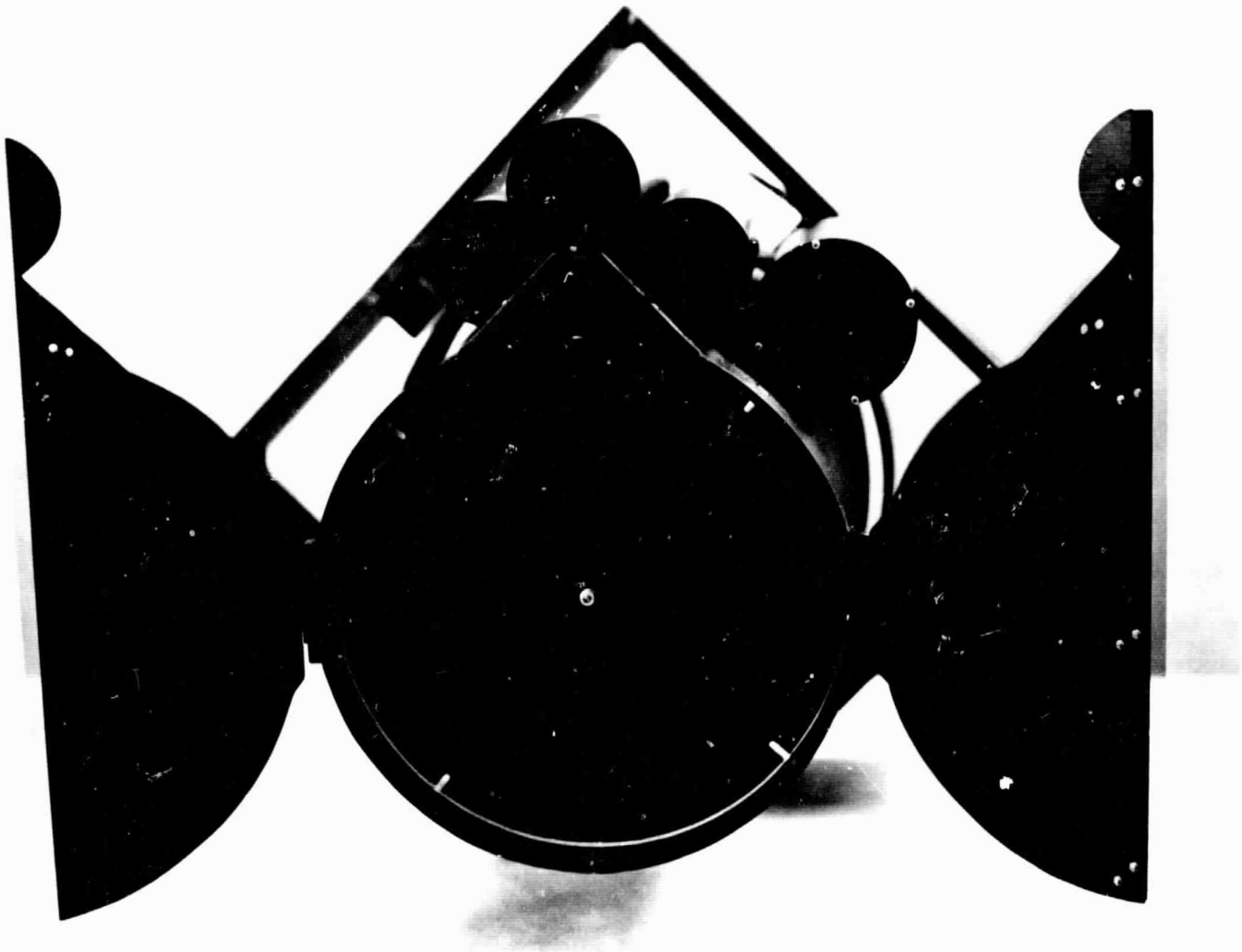
GENERAL INSTRUMENT, INC
AT
LITTLE FALLS, NEW JERSEY

SCHEMATIC DIAGRAM, GYROSCOPE INTEGRATING

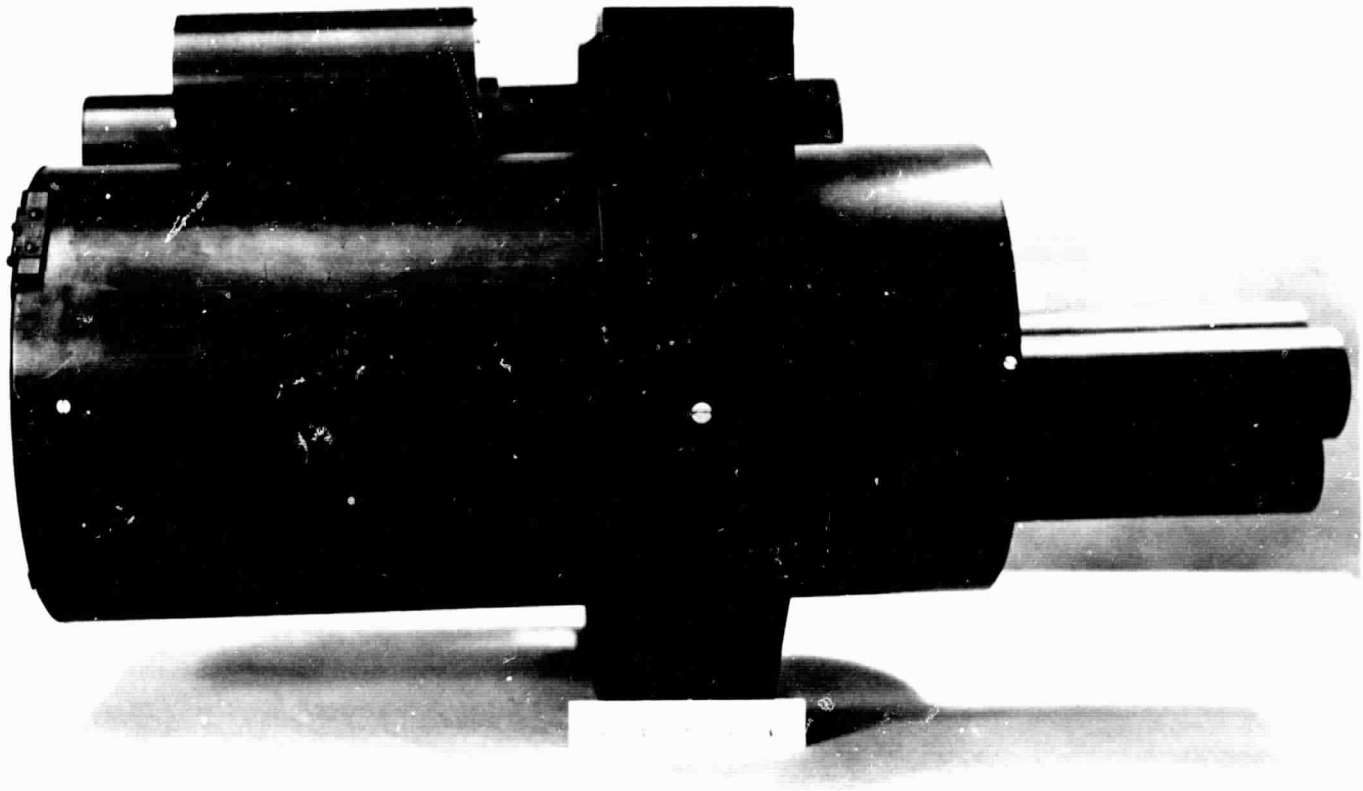
CODE IDENT NO	SIZE	DRAWING NO
88818	C	C543003439
SCALE NONE		SHEET



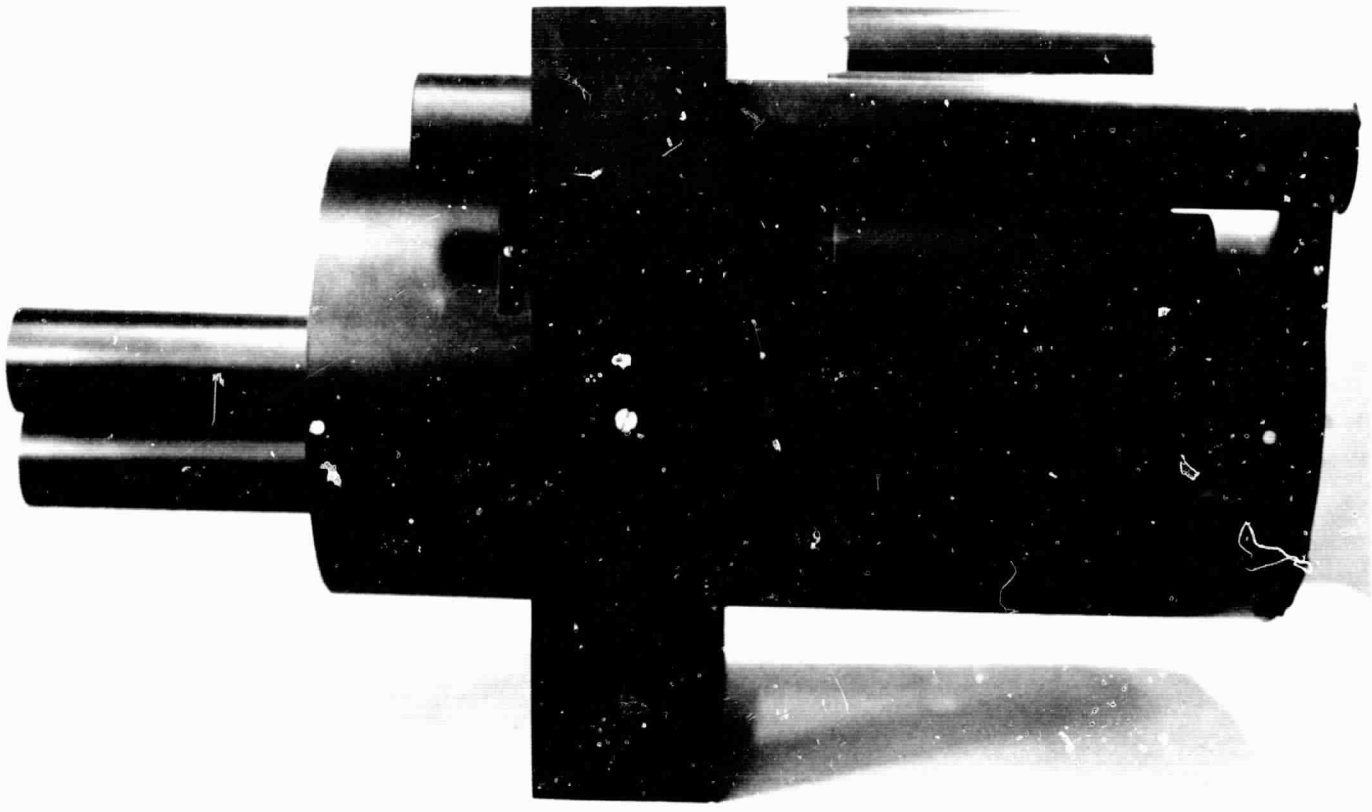
MOCKUP - QUARTER VIEW



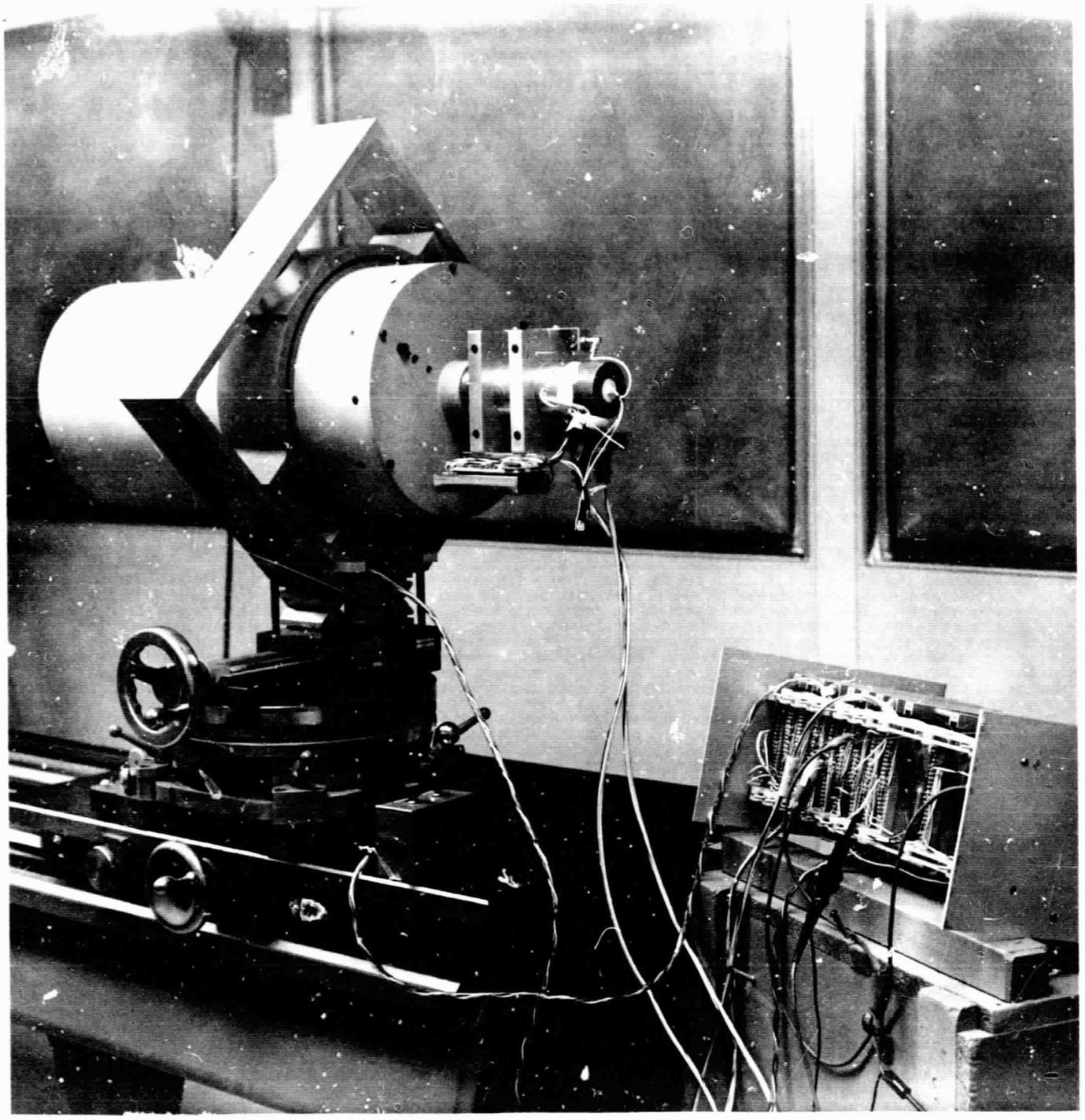
MOCKUP - FRONT VIEW



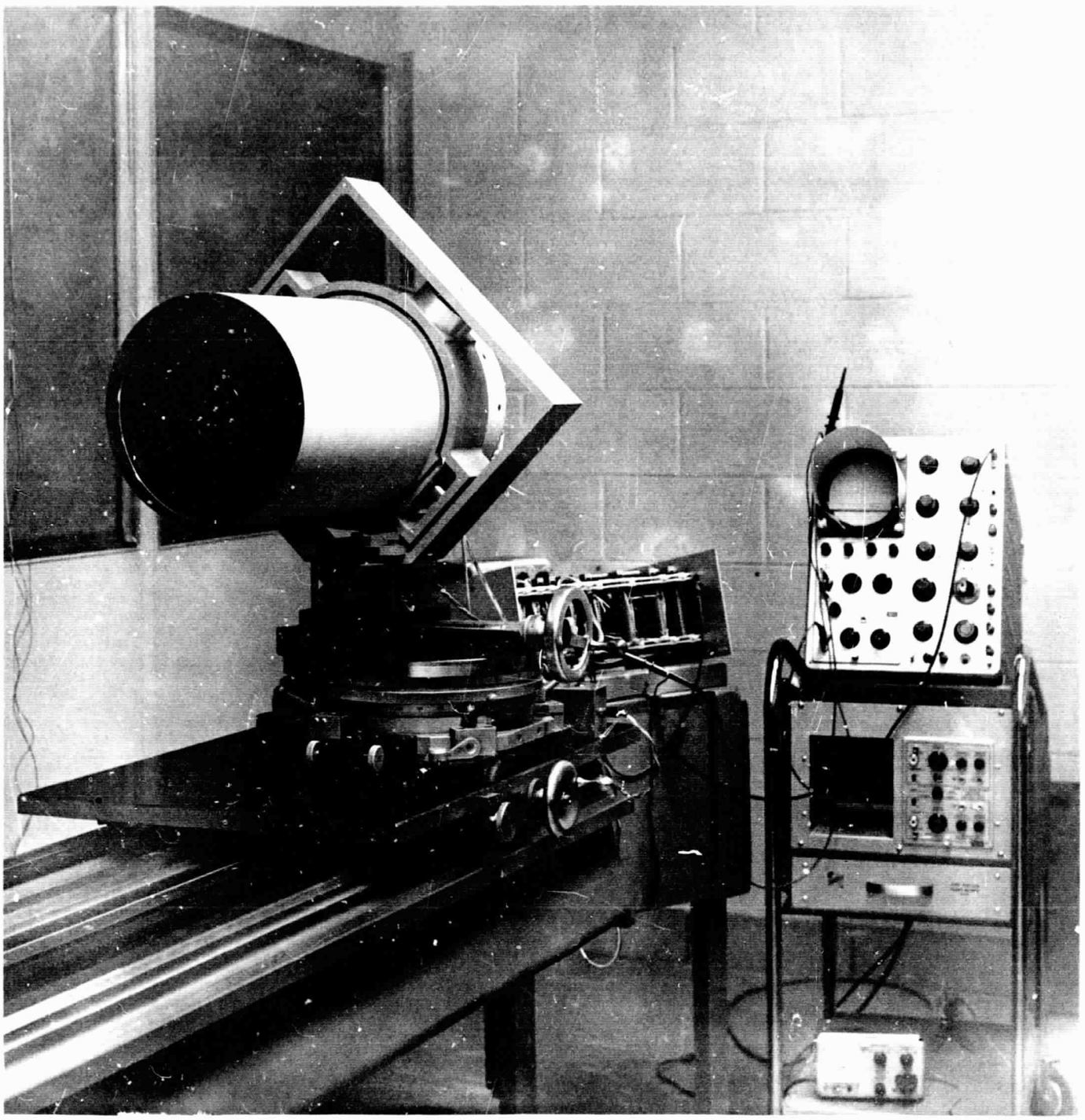
MOCKUP - LEFT SIDE



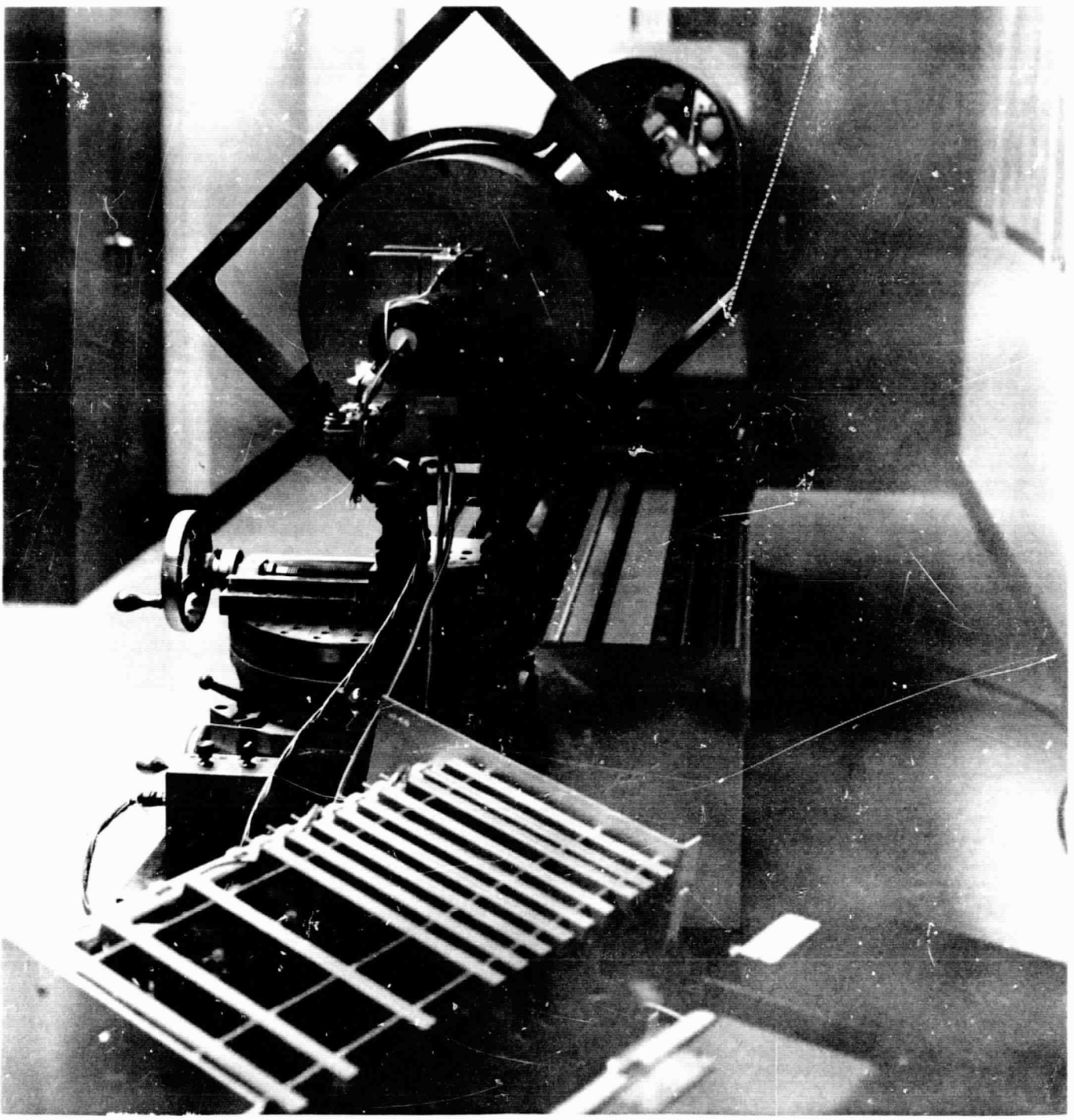
MOCKUP - RIGHT SIDE



BRASSBOARD - REAR QUARTER VIEW



BRASSBOARD - FRONT QUARTER VIEW

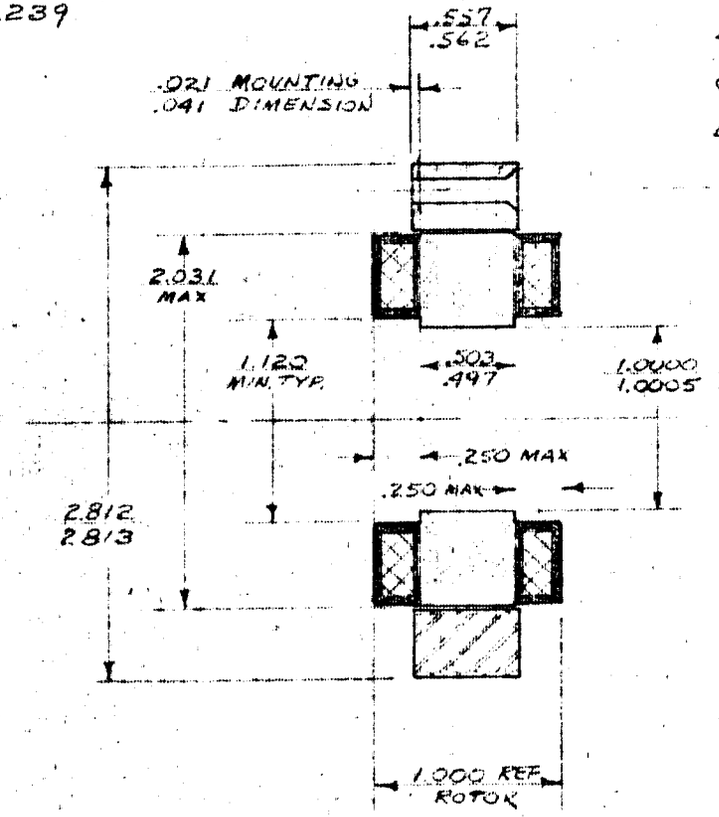


BRASSBOARD - REAR VIEW SHOWING
LENS BENCH

ALL DIMENSIONS PLUS OR MINUS UNLESS OTHERWISE SPECIFIED

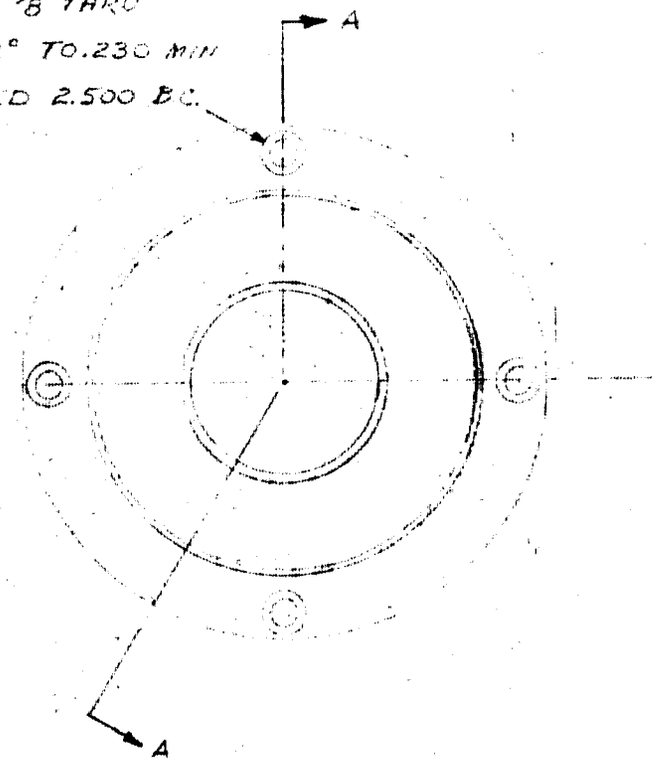
ACTUAL DIMENSIONS:

2.8120	.500
2.8123	.500
2.8120 - 2.8125	.501
.245	.242
.245	.239
.245	.239
1.0004	
1.0002	
1.0004	



SECTION A-A

4 HOLES 1/8 THRU
C'SINK 82° TO.230 MIN
EQ SPACED 2.500 B.C.



LET.	CHANGES	DATE
D		
C		
B		
A		

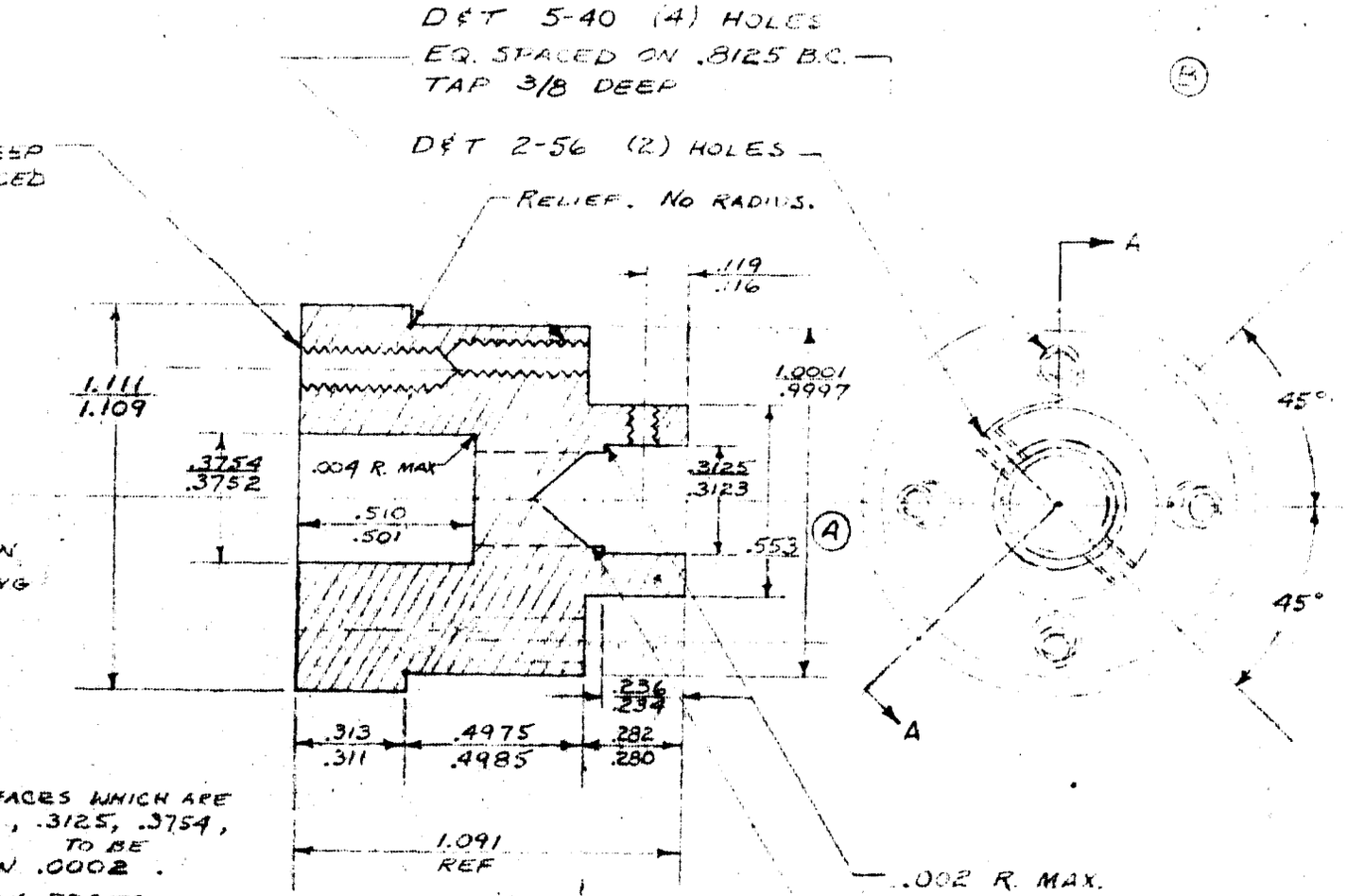
NAME MOTOR T-2170

SCALE	MATERIAL	PROJECT NO.
FULL		01114
DR. BY F³	CK'D. BY	FOR ASSEMBLY
1-17-68		

HIGH ALTITUDE ENGINEERING LABORATORY
DEPARTMENT OF AERONAUTICAL ENGINEERING
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

DRAWING NO.: HI-52001

ALL DIMENSIONS PLUS OR MINUS — UNLESS OTHERWISE SPECIFIED



NOTE (A): THIS DIMENSION TO BE .001 LESS THAN MATING HOLE IN HI-52005

NOTES:
1. SURFACES WHICH ARE DIMENSIONED 1.0001, .3125, .3754, TO BE CONCENTRIC WITHIN .0002.
2. BREAK EDGES.
3. TAPPED THREADS TO BE OF MIL-SPEC QUALITY.

SECTION A-A

B			NAME ROTOR SHAFT		
C			SCALE 2/1 FULL	MATERIAL 7075-T6	PROJECT NO. 01114
D	# HOLES REVISED	3-12-68	DR. BY F3	CKD. BY	FOR ASSEMBLY
E	ADD SEE "I" NOTE ADDED	3-12-68	DATE 1-17-68		

HIGH ALTITUDE ENGINEERING LABORATORY
DEPARTMENT OF AERONAUTICAL ENGINEERING
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

DRAWING NO.: HI-52002

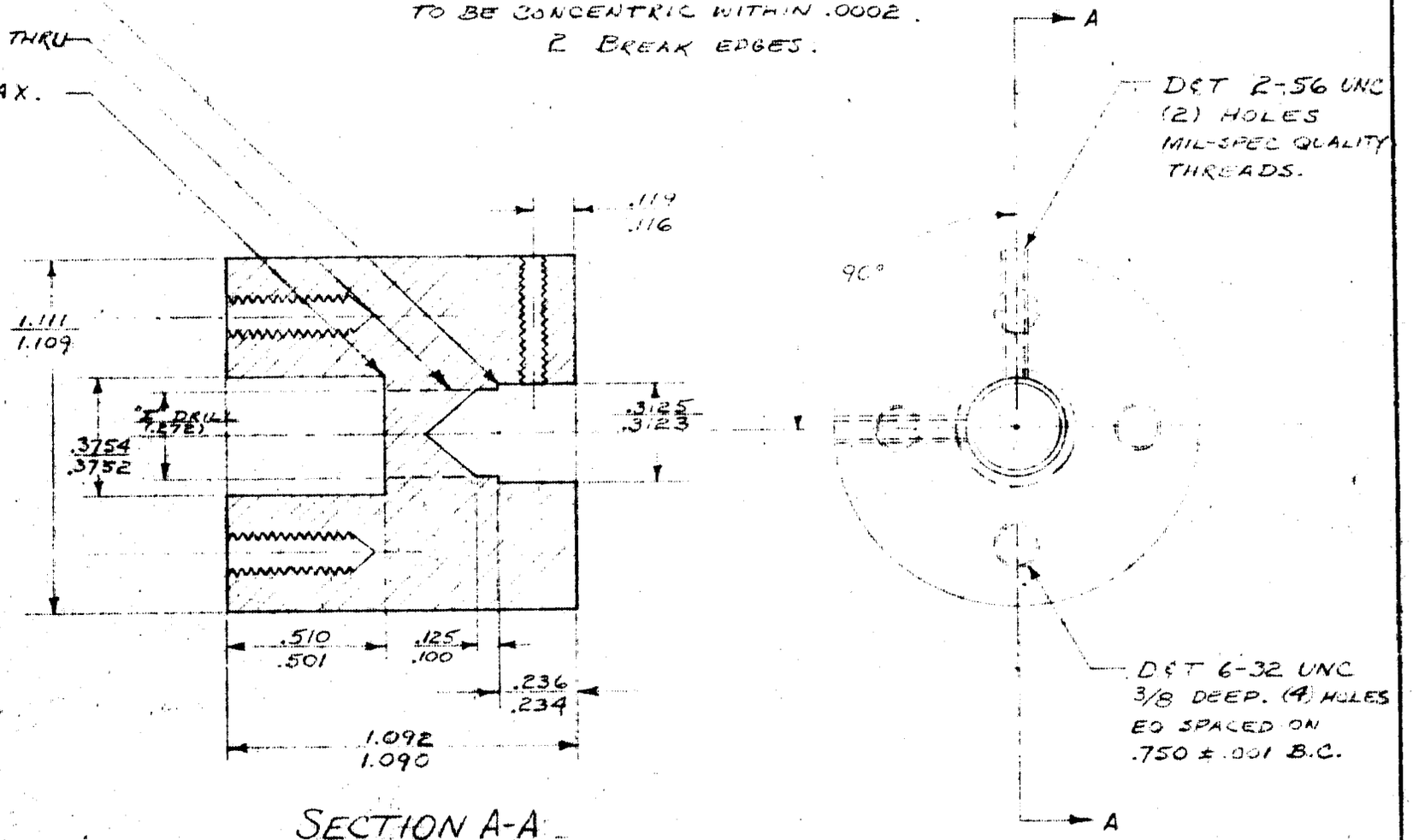
ALL DIMENSIONS PLUS OR MINUS UNLESS OTHERWISE SPECIFIED

.002 R. MAX.

OPTIONAL D. THRU

.004 R. MAX.

NOTES: 1. PRECISION HOLES (2) TO BE CONCENTRIC WITHIN .0002.
2. BREAK EDGES.



SECTION A-A

LTR	CHANGES	DATE
D		
C		
B		
A		

NAME DUMMY SHAFT

SCALE	MATERIAL	PROJECT NO.
2 X FULL	7075-T6	01114
DR. BY JF 3	CK'D. BY	FOR ASSEMBLY
1-19-68		

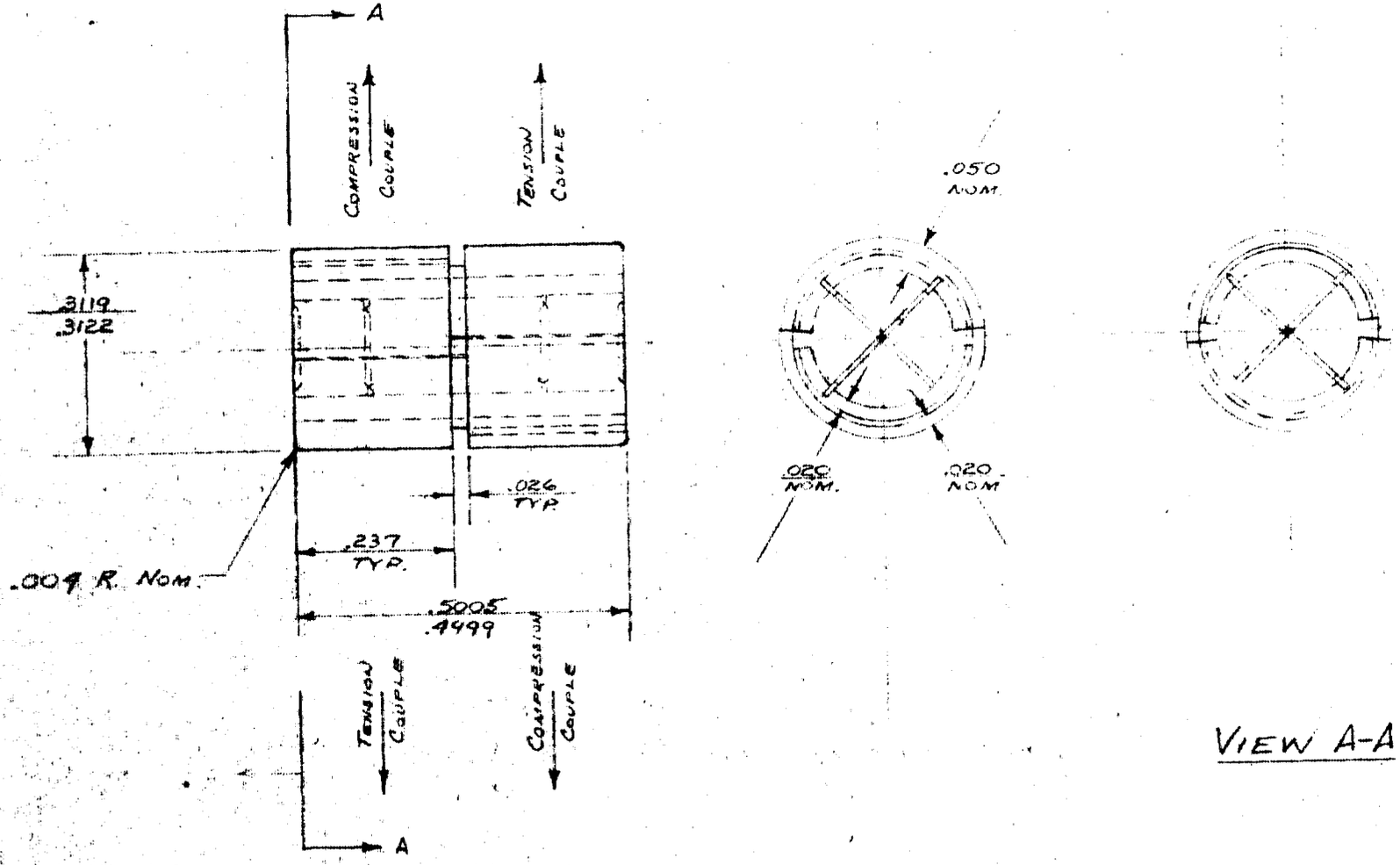
HIGH ALTITUDE ENGINEERING LABORATORY
DEPARTMENT OF AERONAUTICAL ENGINEERING
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

DRAWING NO.: HI-52003

ALL DIMENSIONS PLUS OR MINUS UNLESS OTHERWISE SPECIFIED

BENDIX - UTICA DIVN.
PART 5010-600

COMPRESSION LIMIT : 55 LB.
TENSION LIMIT : 78 LB.
SPRING RATE - NO LOAD: 1.64 LB-IN/RADIAN
MAX. DEFLECTION : ± 15°

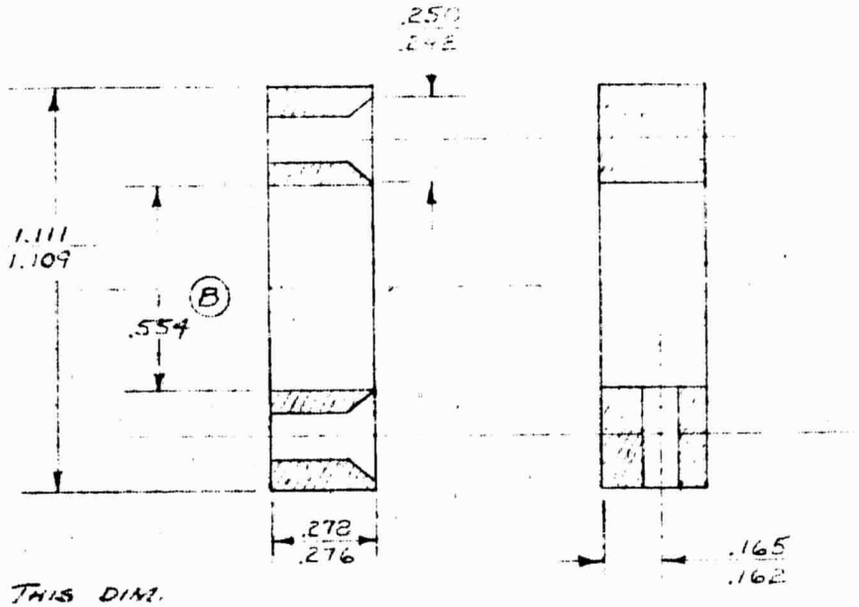


VIEW A-A

D		NAME FLEX-PIVOT		HIGH ALTITUDE ENGINEERING LABORATORY DEPARTMENT OF AERONAUTICAL ENGINEERING UNIVERSITY OF MICHIGAN ANN ARBOR, MICHIGAN
C		SCALE 4 X FULL	MATERIAL CRS	PROJECT NO. 01114
B		DR. BY F 3	CH'KD. BY	FOR ASSEMBLY
A		1-19-68		DRAWING NO.: H1-52004
LTR	CHANGES	DATE		

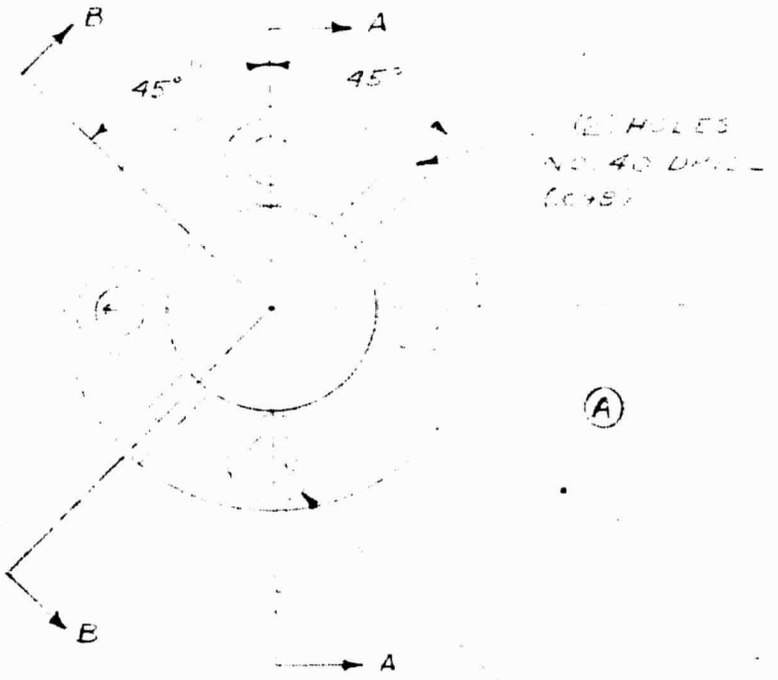
ALL DIMENSIONS PLUS OR MINUS UNLESS OTHERWISE SPECIFIED

NOTES:
1. BREAK EDGES.
2. ALL HOLE LOCATIONS ±.001 UNLESS SPECIFIED



NOTE B THIS DIM. TO BE .001 LARGER THAN MATING DIAM. ON PART HI-52002

SECTION A-A



SECTION B-B

(4) HOLES
NO. 29 DRILL (.136)
C'SINK 82° EQUALLY
SPACED .8125 ±.001 B.C.

LET.	CHANGES	DATE
D		
C		
B	WAS 3/8 & NOTE ADDED	3-12-8
A	2 HOLES REMOVED	5-12-8

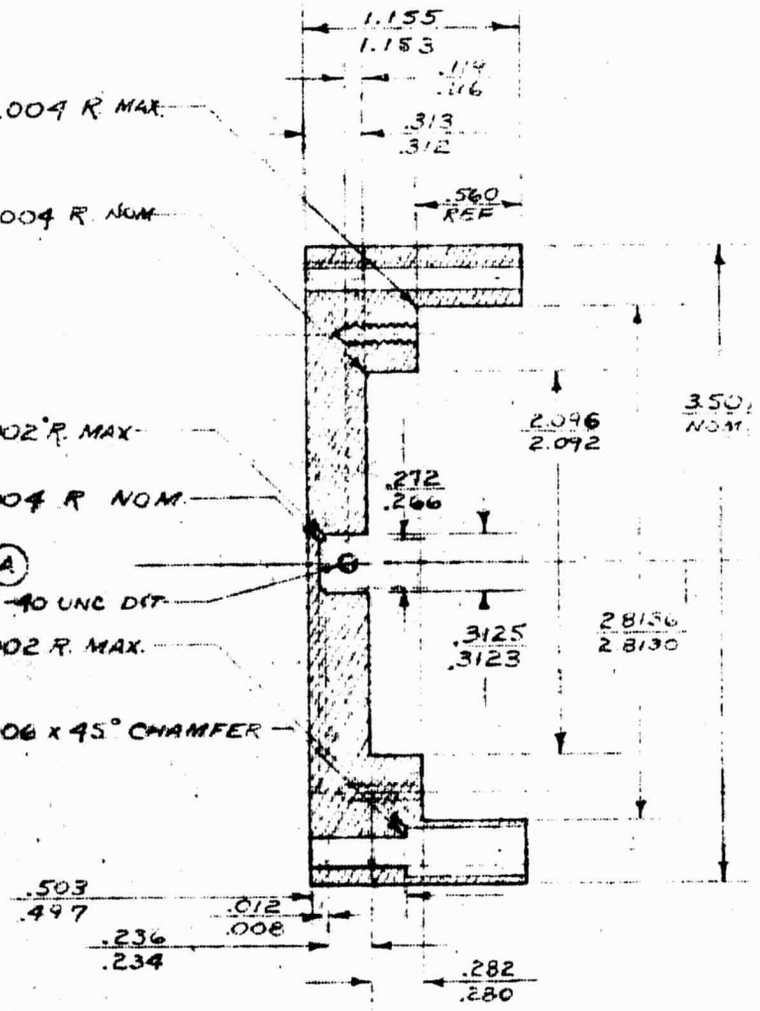
NAME RING, ROTOR CLAMP

SCALE	MATERIAL	PROJECT NO.
2 X FULL	7075-T6	01114
DR. BY F3	CK'D. BY	FOR ASSEMBLY
1-23-68		

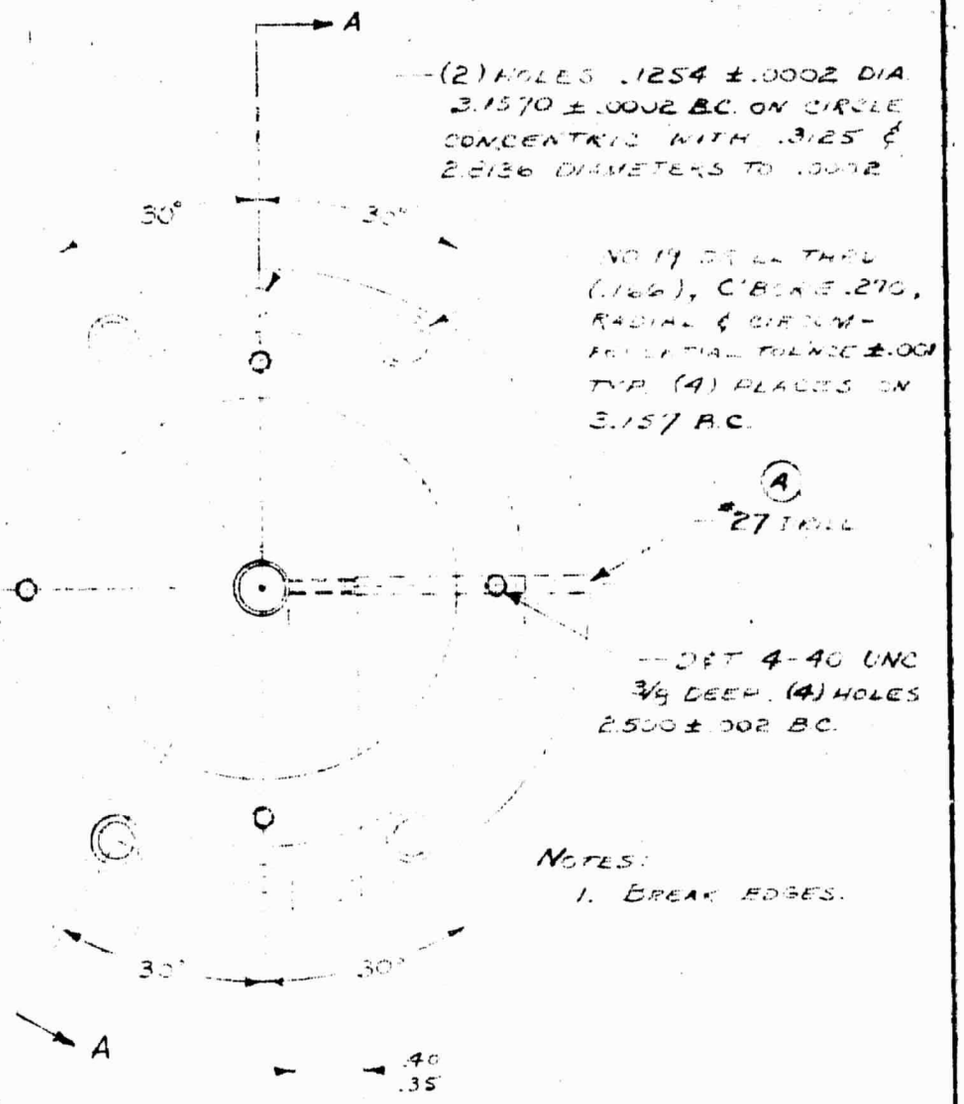
HIGH ALTITUDE ENGINEERING LABORATORY
DEPARTMENT OF AERONAUTICAL ENGINEERING
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

DRAWING NO.: HI-52005

ALL DIMENSIONS PLUS OR MINUS .002 UNLESS OTHERWISE SPECIFIED



SECTION A-A



LET.	CHANGES	DATE
D		
C		
B		
A	WAS #41 D. ℄ 2-56	3-12-68

NAME FIELD CUP

SCALE	MATERIAL	PROJECT NO.
FULL	7075-T6	01114
DR. BY F³	CK'D. BY	FOR ASSEMBLY
1-19-68		

HIGH ALTITUDE ENGINEERING LABORATORY
DEPARTMENT OF AERONAUTICAL ENGINEERING
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

DRAWING NO.: HI-52006

ALL DIMENSIONS PLUS OR MINUS

UNLESS OTHERWISE SPECIFIED

NOTES:
1. BREAK EDGES.

(2) HOLES .1254 ± .0002 DIA. 3.1570 ± .0002 B.C. ON CIRCLE CONCENTRIC WITH .3125 H.LE TO .0002

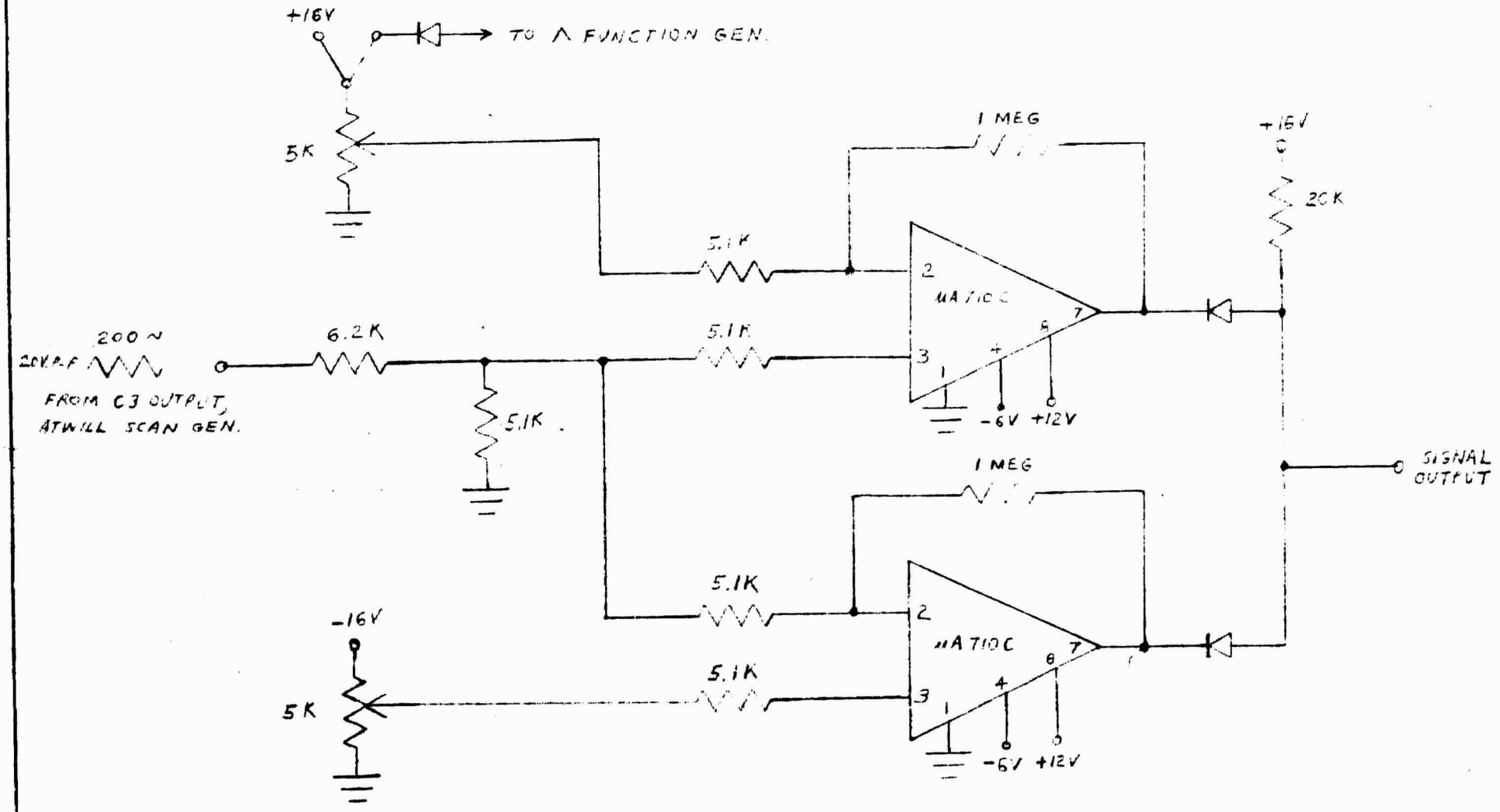
.62 R. MAX.

.004 R. NOM.

D			NAME PIVOT MOUNT		HIGH ALTITUDE ENGINEERING LABORATORY DEPARTMENT OF AERONAUTICAL ENGINEERING UNIVERSITY OF MICHIGAN ANN ARBOR, MICHIGAN
C			SCALE FULL	MATERIAL 7075-T6	PROJECT NO. 0114
B			DR. BY F.J.	O'KD. BY	FOR ASSEMBLY
A	WAS "4" D. 5 2-1-62	3-12-62	1-20-62		DRAWING NO: H1-52007
LET	CHANGES	DATE			

ALL DIMENSIONS PLUS OR MINUS

UNLESS OTHERWISE SPECIFIED



LET.	CHANGES	DATE
D		
C		
B		
A		

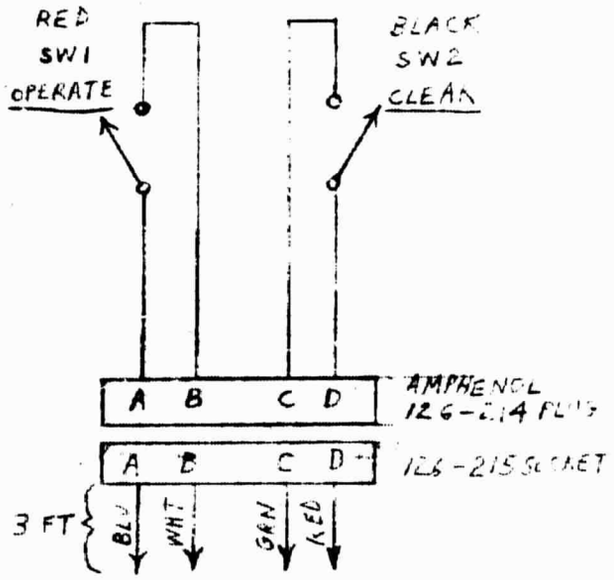
NAME TEST CIRCUIT - PRE-AMP SIGNAL SIMULATOR

SCALE	MATERIAL	PROJECT NO.
NONE		0114
DR. BY T.R.P	O'KD. BY	FOR ASSEMBLY
4-29-68		

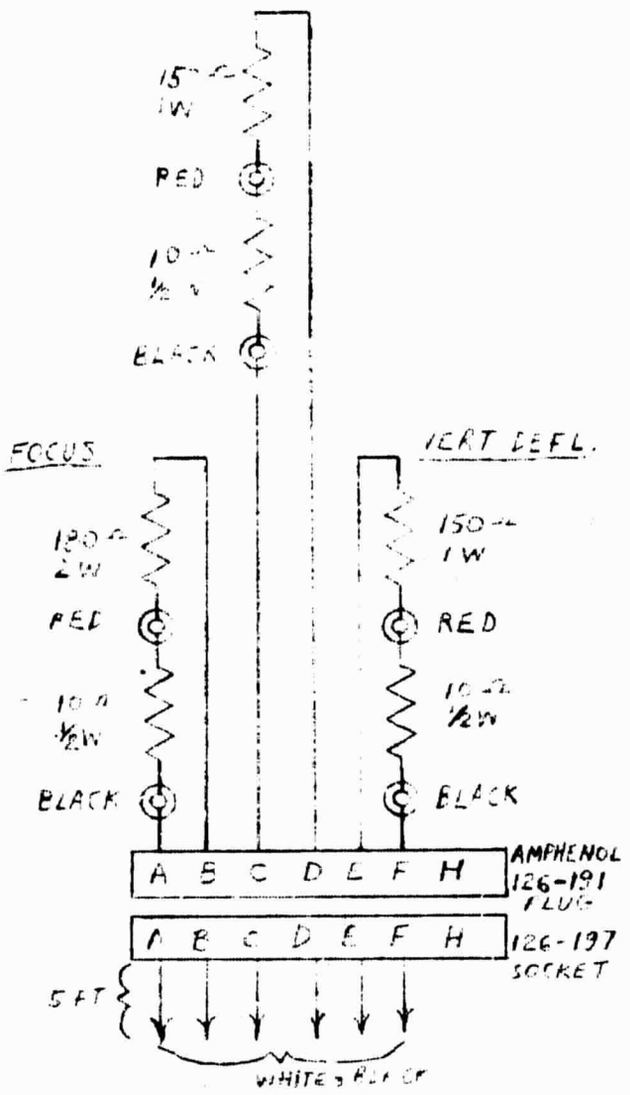
HIGH ALTITUDE ENGINEERING LABORATORY
DEPARTMENT OF AERONAUTICAL ENGINEERING
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

DRAWING NO.: HI-52008

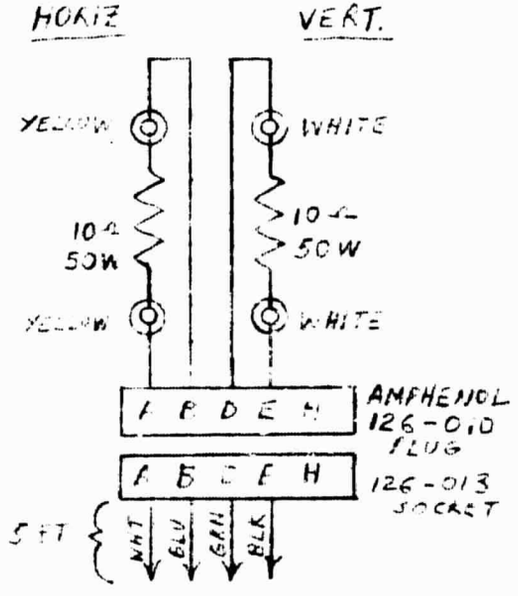
ALL DIMENSIONS PLUS OR MINUS UNLESS OTHERWISE SPECIFIED



OPERATE - CLEAR CONTROL BOX



FOCUS REG. & DEFL. COIL DRIVER DUMMY LOADS BOX



HORIZ. & VERT. TORQUE MOTOR DUMMY LOAD

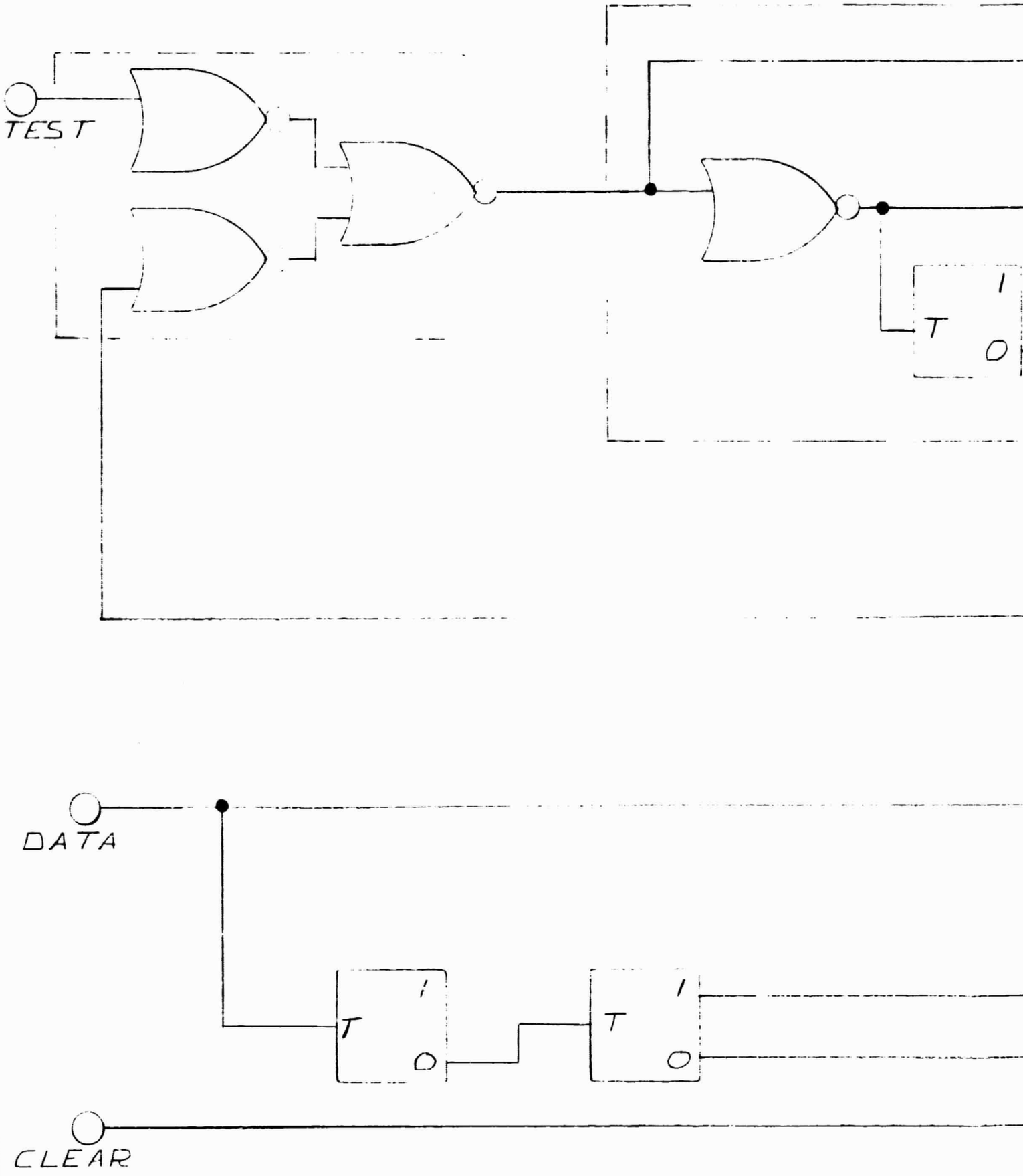
LET.	CHANGES	DATE
D		
C		
B		
A		

NAME 3 TEST BOXES - CONTROL & DUMMY LOADS

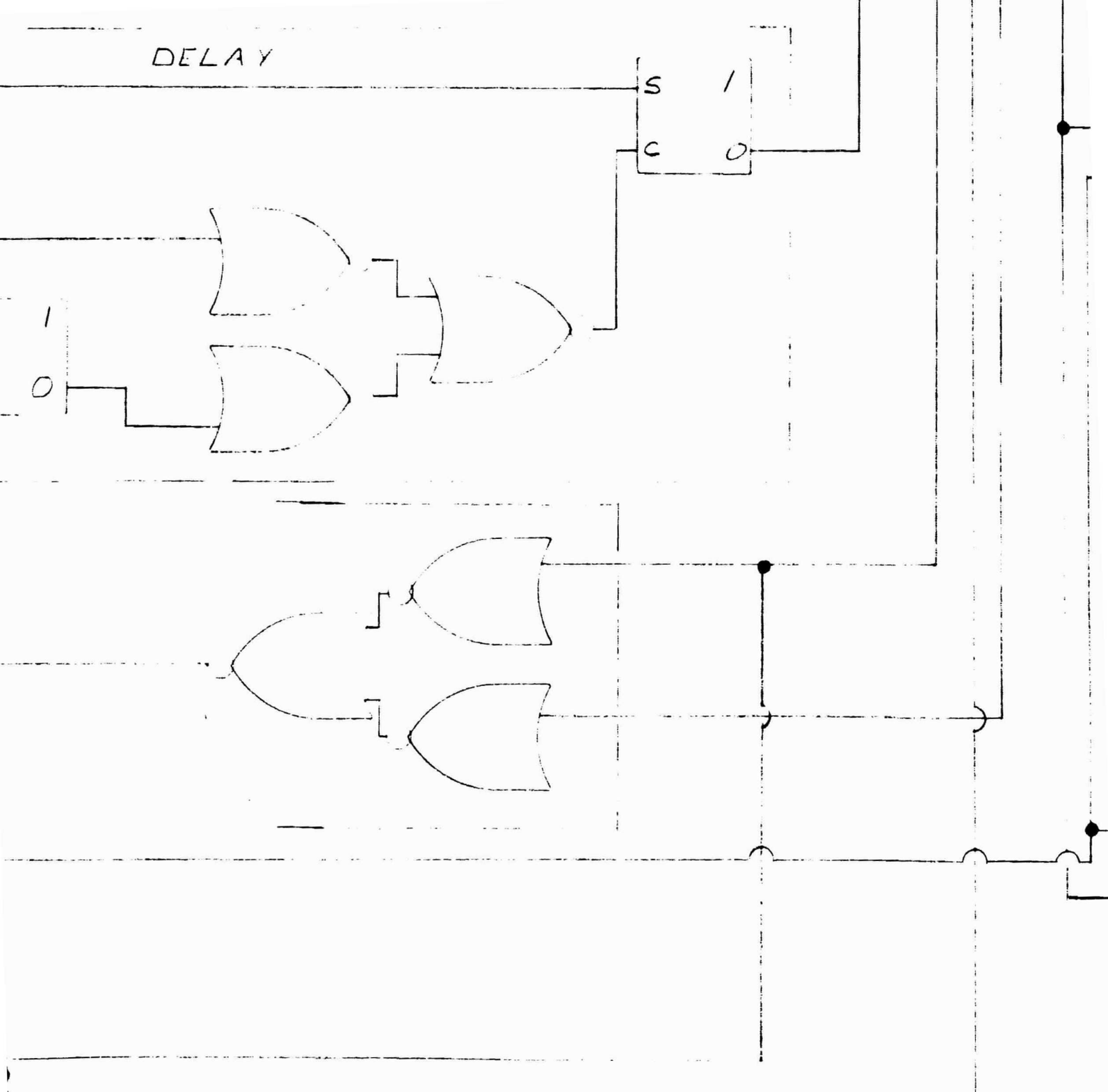
SCALE	MATERIAL	PROJECT NO.
NONE		01114
DR. BY TRP	O'KD. BY	FOR ASSEMBLY
4-29-68		

HIGH ALTITUDE ENGINEERING LABORATORY
DEPARTMENT OF AERONAUTICAL ENGINEERING
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

DRAWING NO.: HI-52009

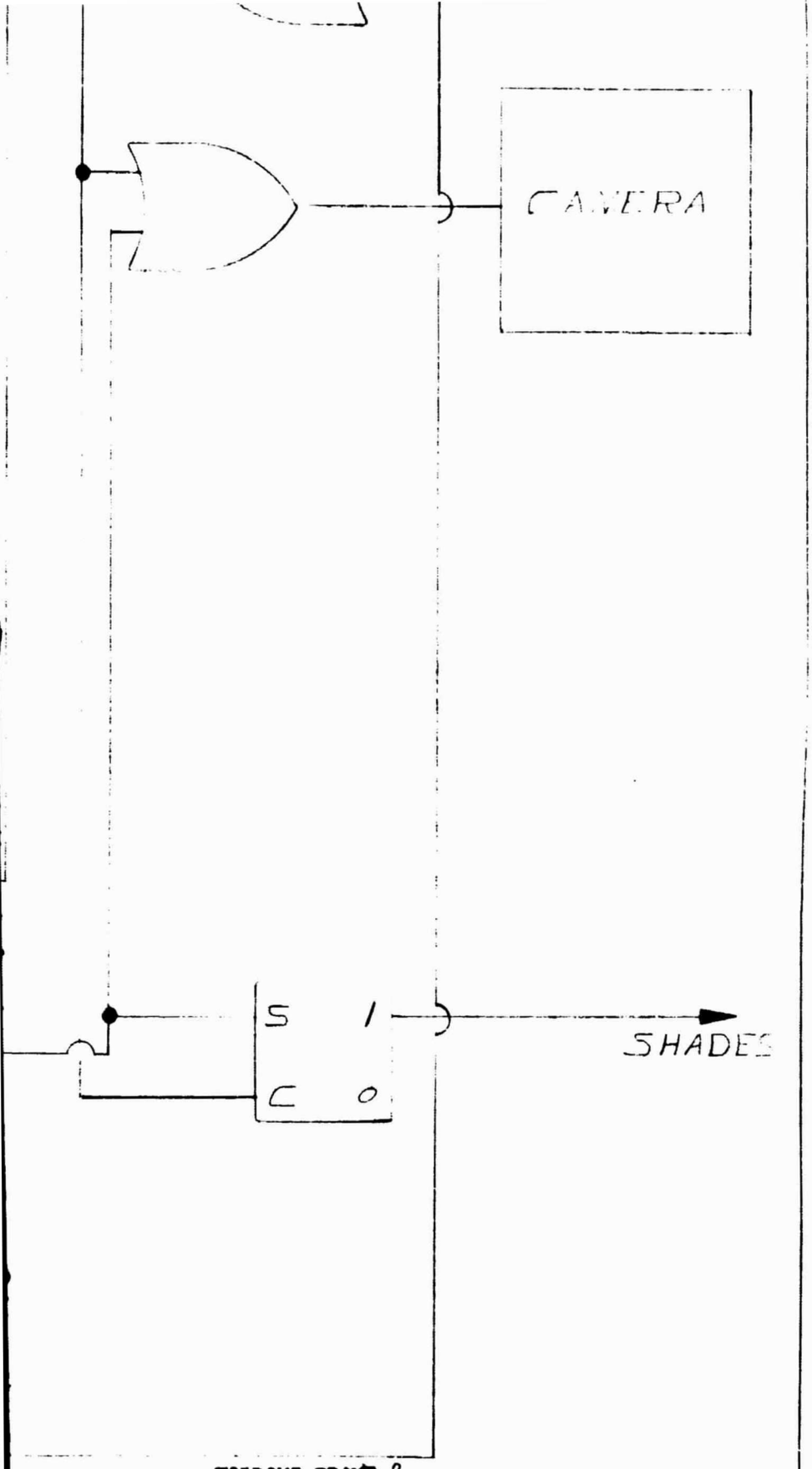


FOLDOUT FRAME 1



			SCALE	NONE
			PROJ. NO	06647
			DRAWN BY	J.C. POUSA
			DATE	4-7-66
			FOR ASSEMBLY	
			DESIGN BY	D.E. HADDO
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

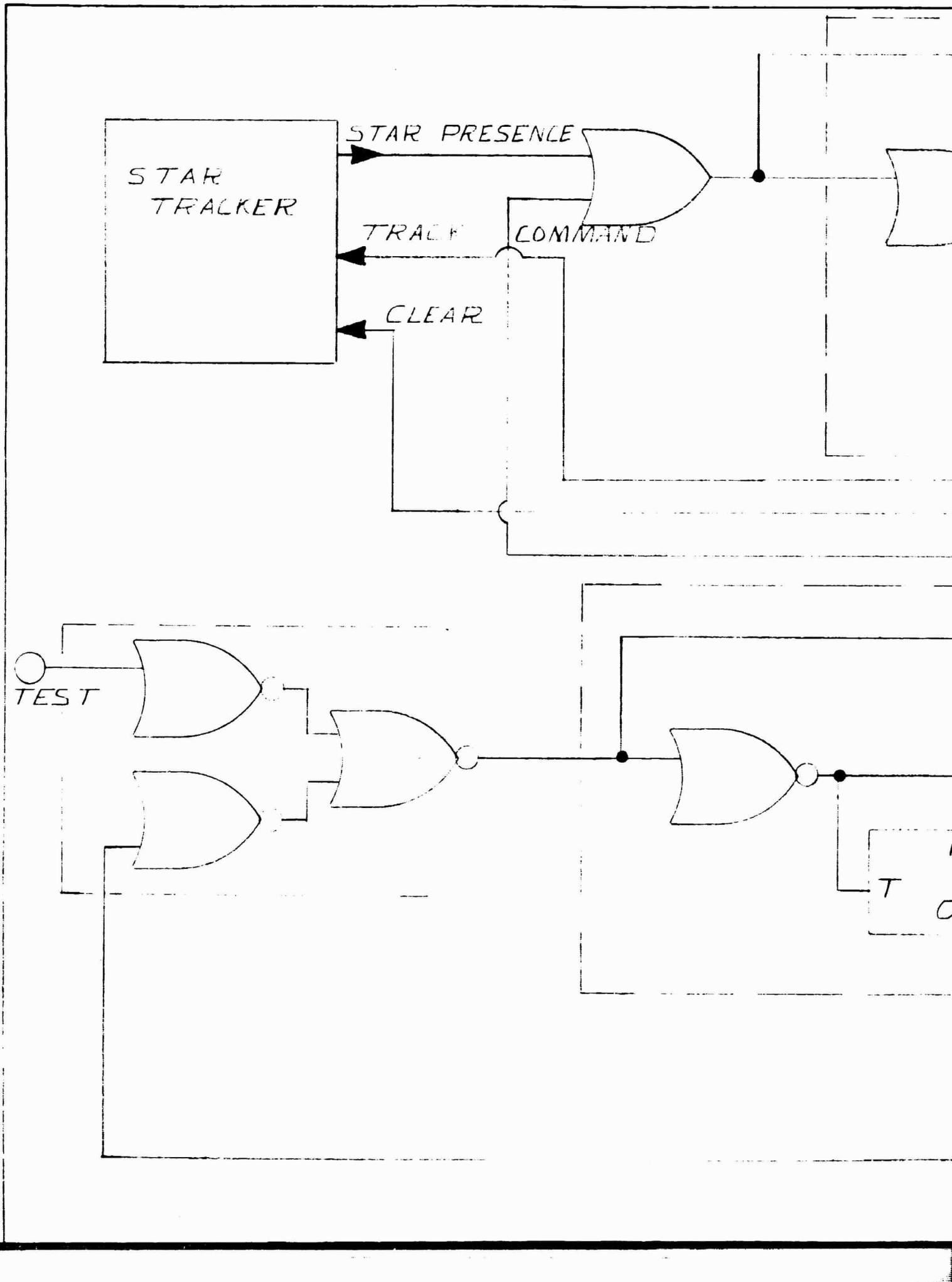
FOLDOUT FRAME 2

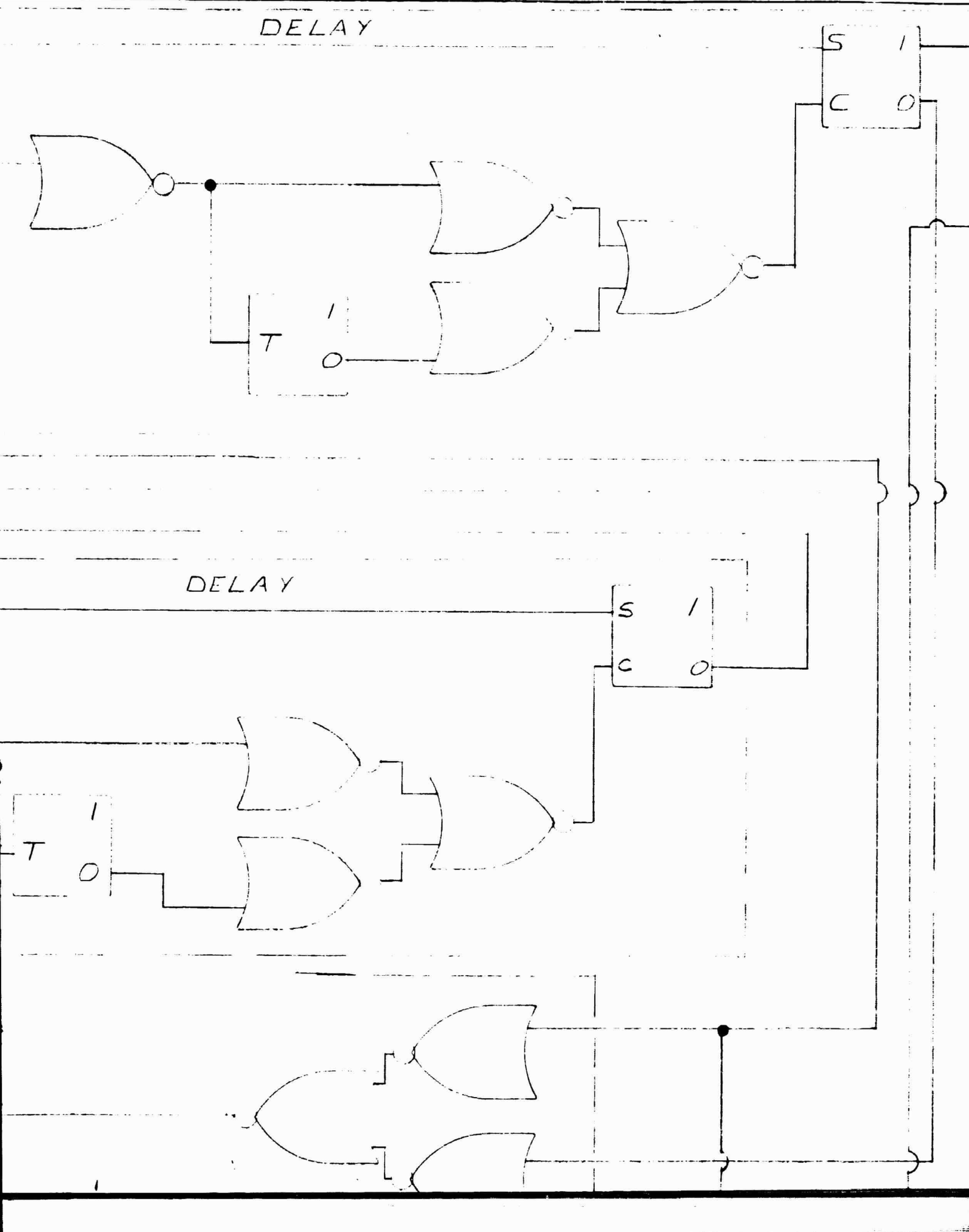


FOLDOUT FRAME 3

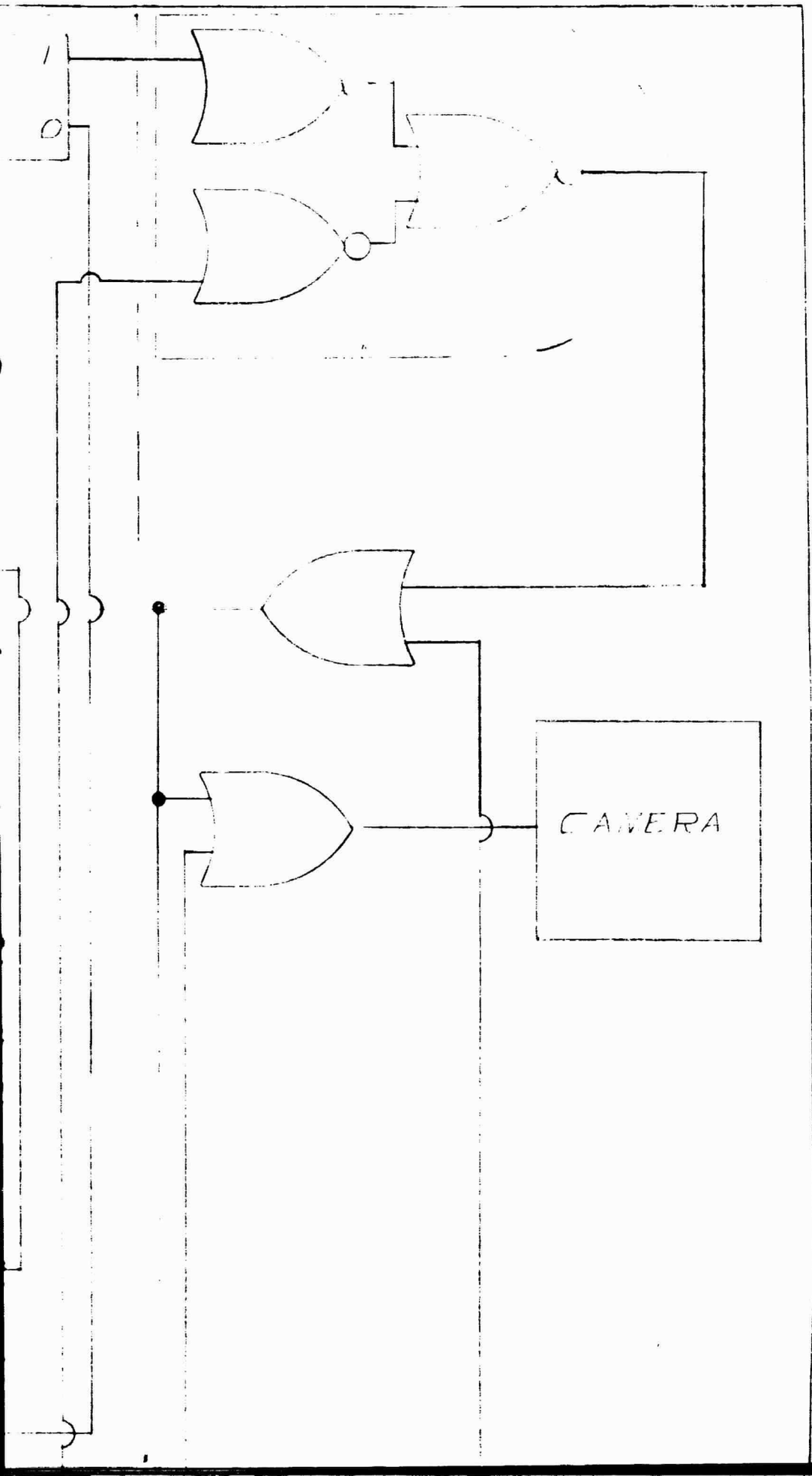
E	HIGH ALTITUDE ENGINEERING LABORATORY UNIVERSITY OF MICHIGAN DEPARTMENT OF AERO. AND ASTRO. ENGINEERING ANN ARBOR MICHIGAN
#7	
POUSAK	
-66	NAME ELECTRONIC GIMBAL CONTROL SYSTEM
ADDOU	DRAWING NO. H3-52001

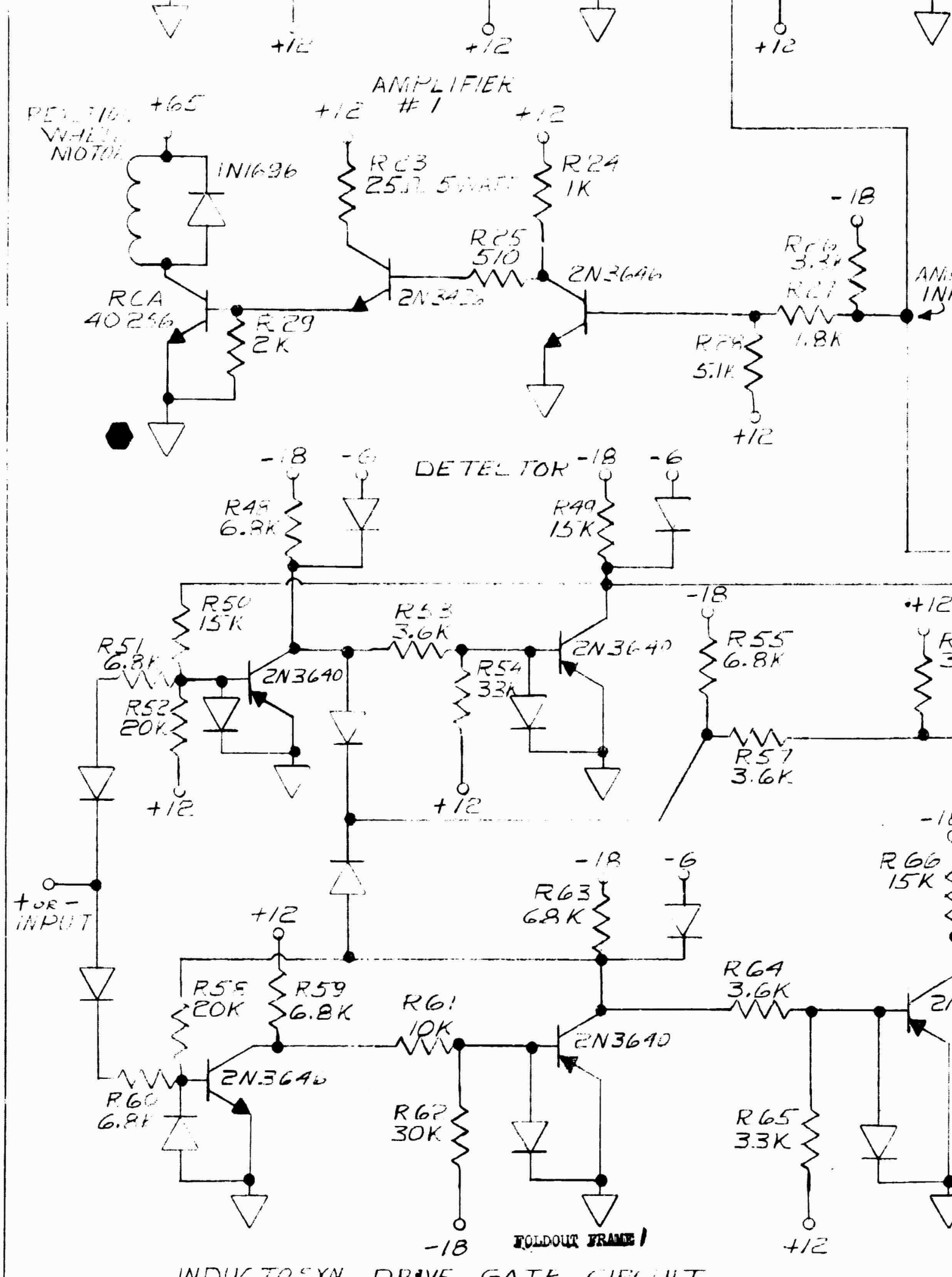
FOLDOUT FRAME 4



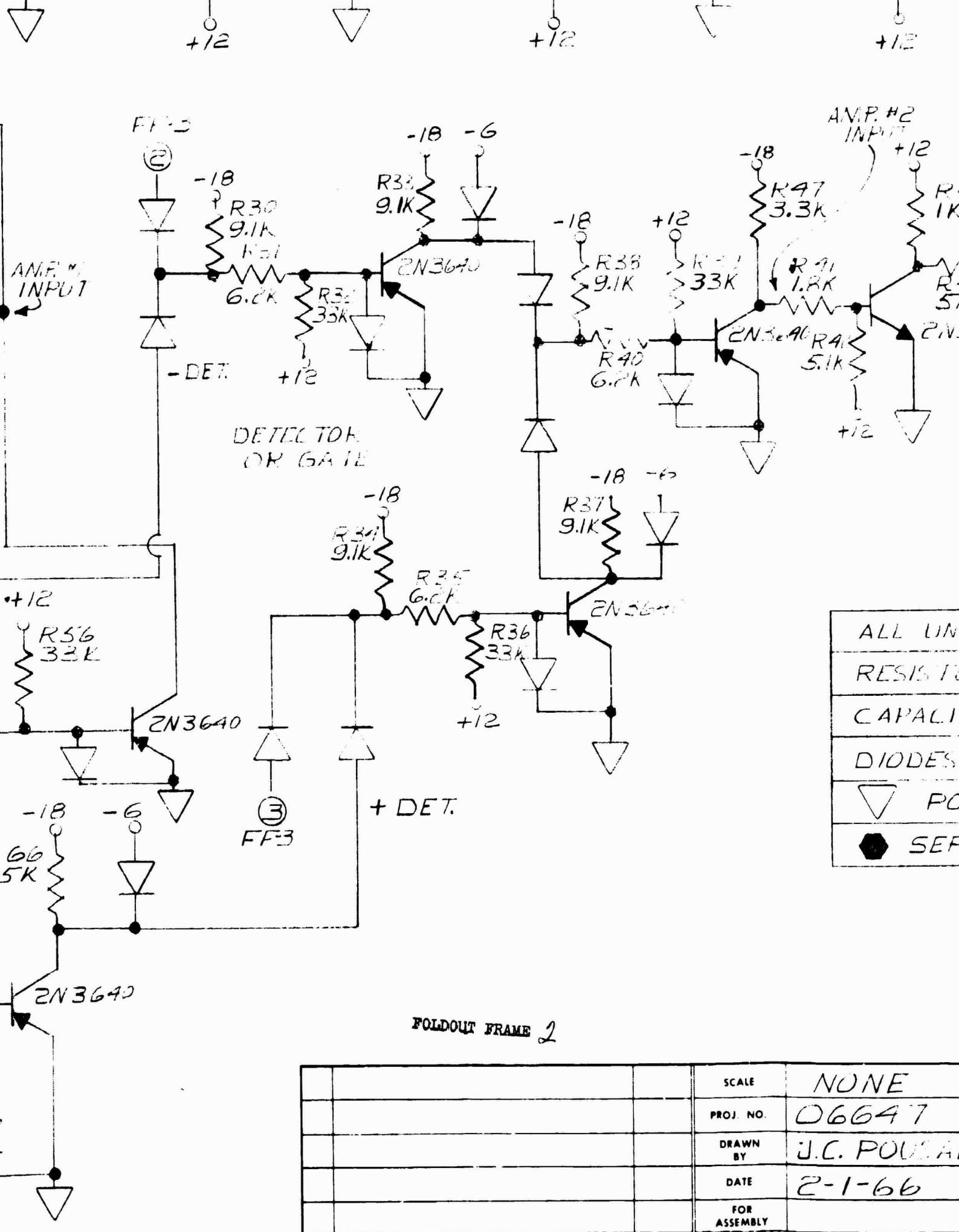

DELAY
S
1
C
0
T
1
0
DELAY
S
1
C
0
T
1
0

FOLDOUT FRAME 6



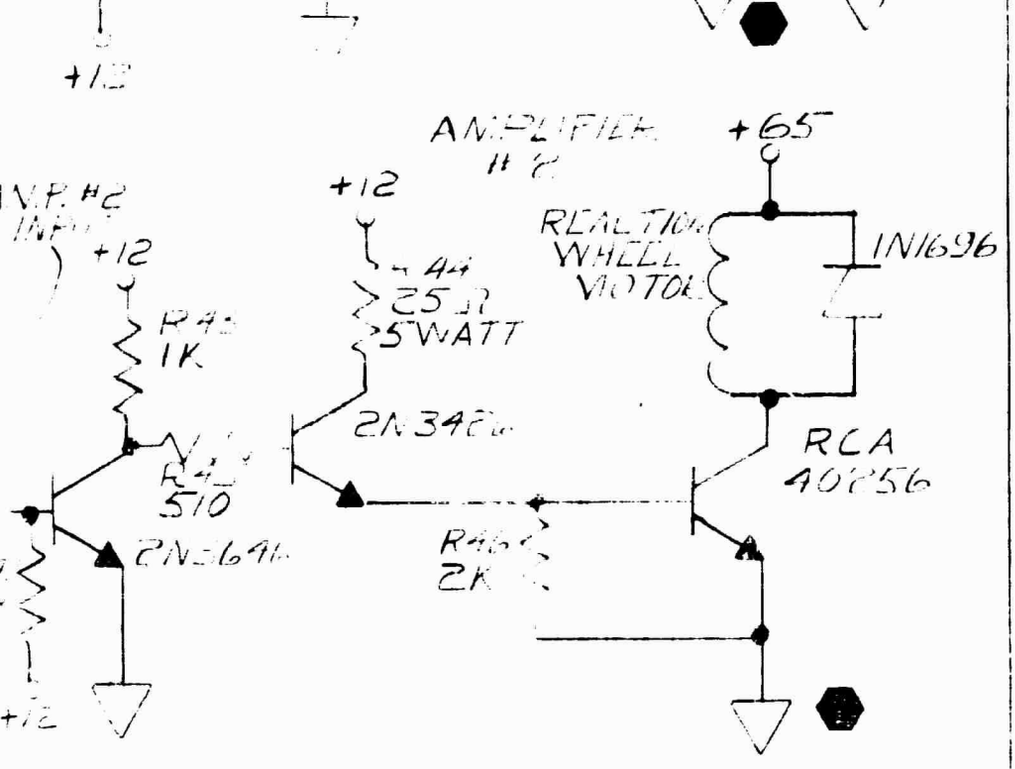


INDUCTOSYN DRIVE GATE CIRCUIT
(DETECTOR)



FOLDOUT FRAME 2

			SCALE	NONE
			PROJ. NO.	06647
			DRAWN BY	J.C. POU
			DATE	2-1-66
			FOR ASSEMBLY	
			DESIGN APPROVAL BY	D. HADDOCK
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	



ALL UNLESS OTHERWISE SPECIFIED

RESISTORS ½ WATT 5%

CAPACITORS 50VOLT ±10%, IN MFD.

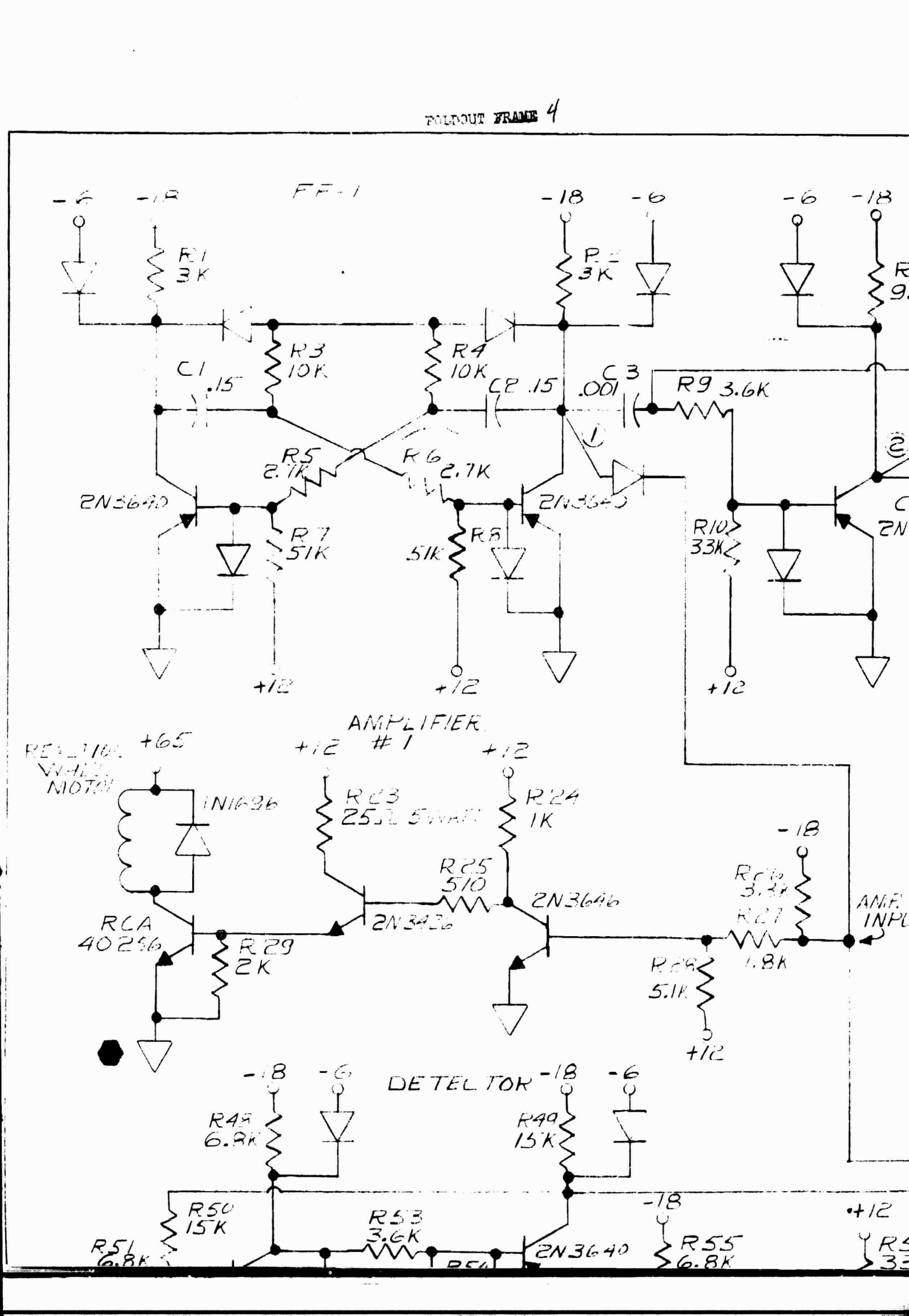
DIODES G.E. IN4154

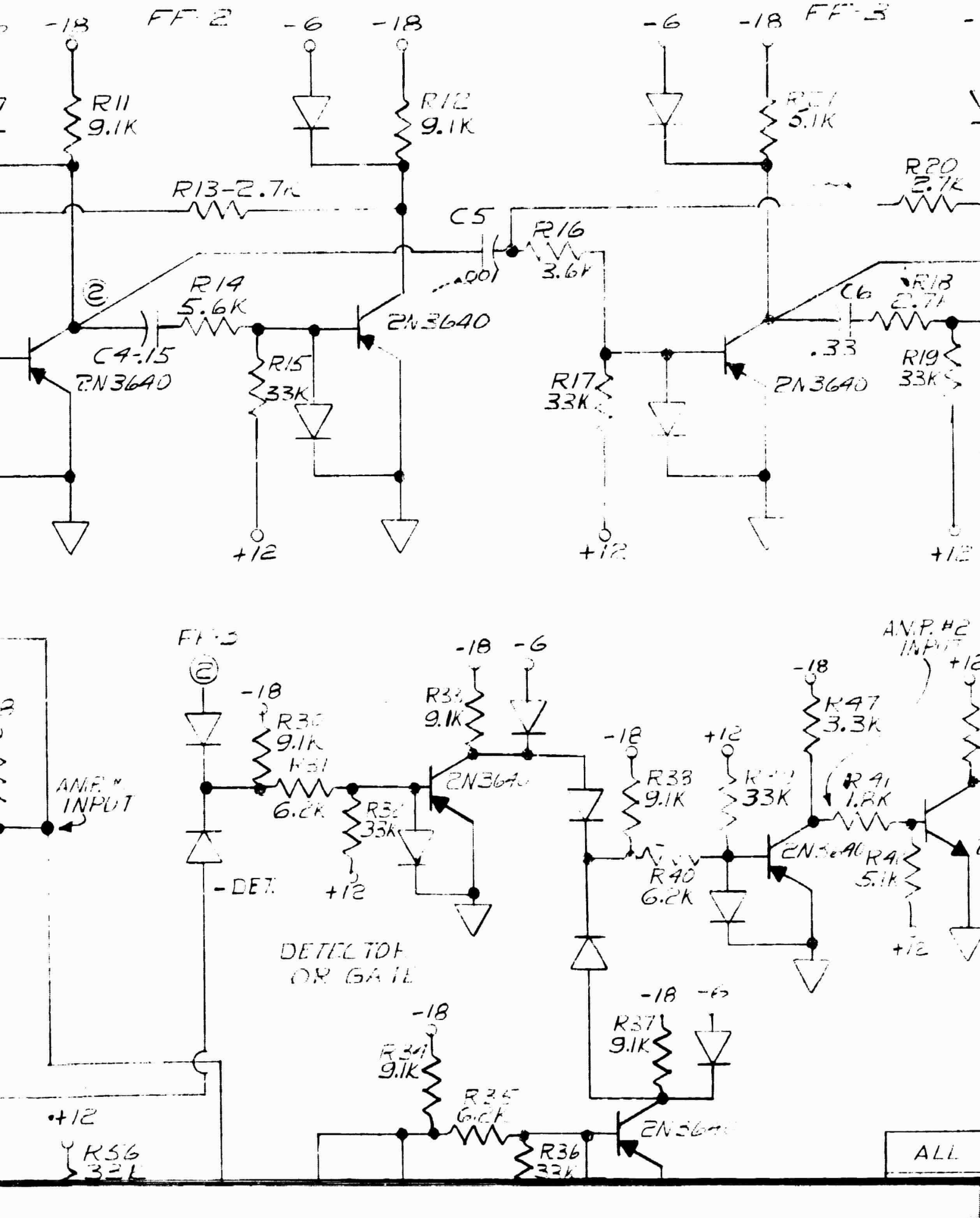
▽ POWER GROUND

● SEPERATE POWER GROUND

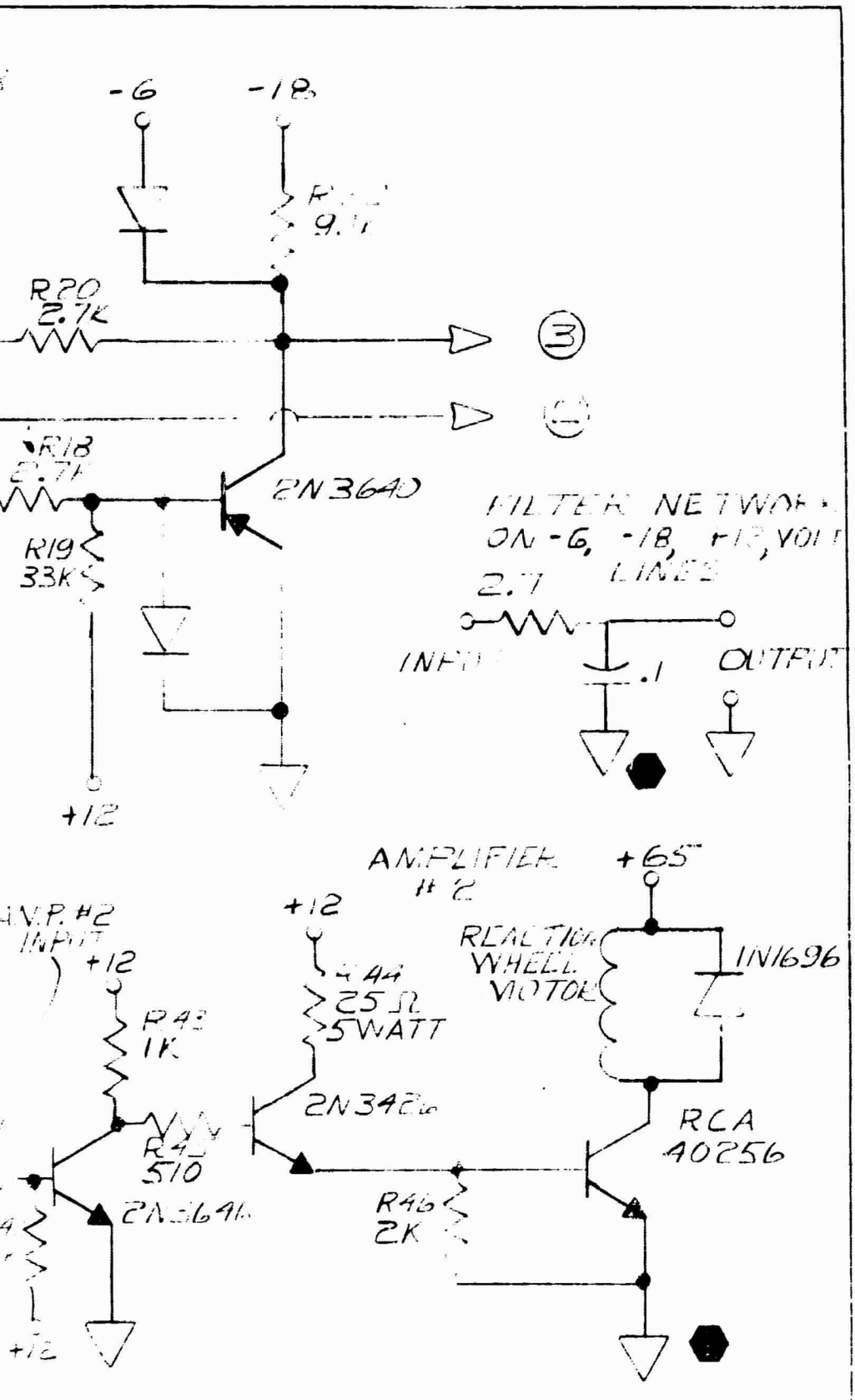
FOLDOUT FRAME 3

ONE	HIGH ALTITUDE ENGINEERING LABORATORY UNIVERSITY OF MICHIGAN DEPARTMENT OF AERO. AND ASTRO. ENGINEERING ANN ARBOR MICHIGAN
6647	
POLAR	
1-66	NAME REACTION WHEEL DRIVE CIRCUIT
HADDOCK	DRAWING NO. H3-52002

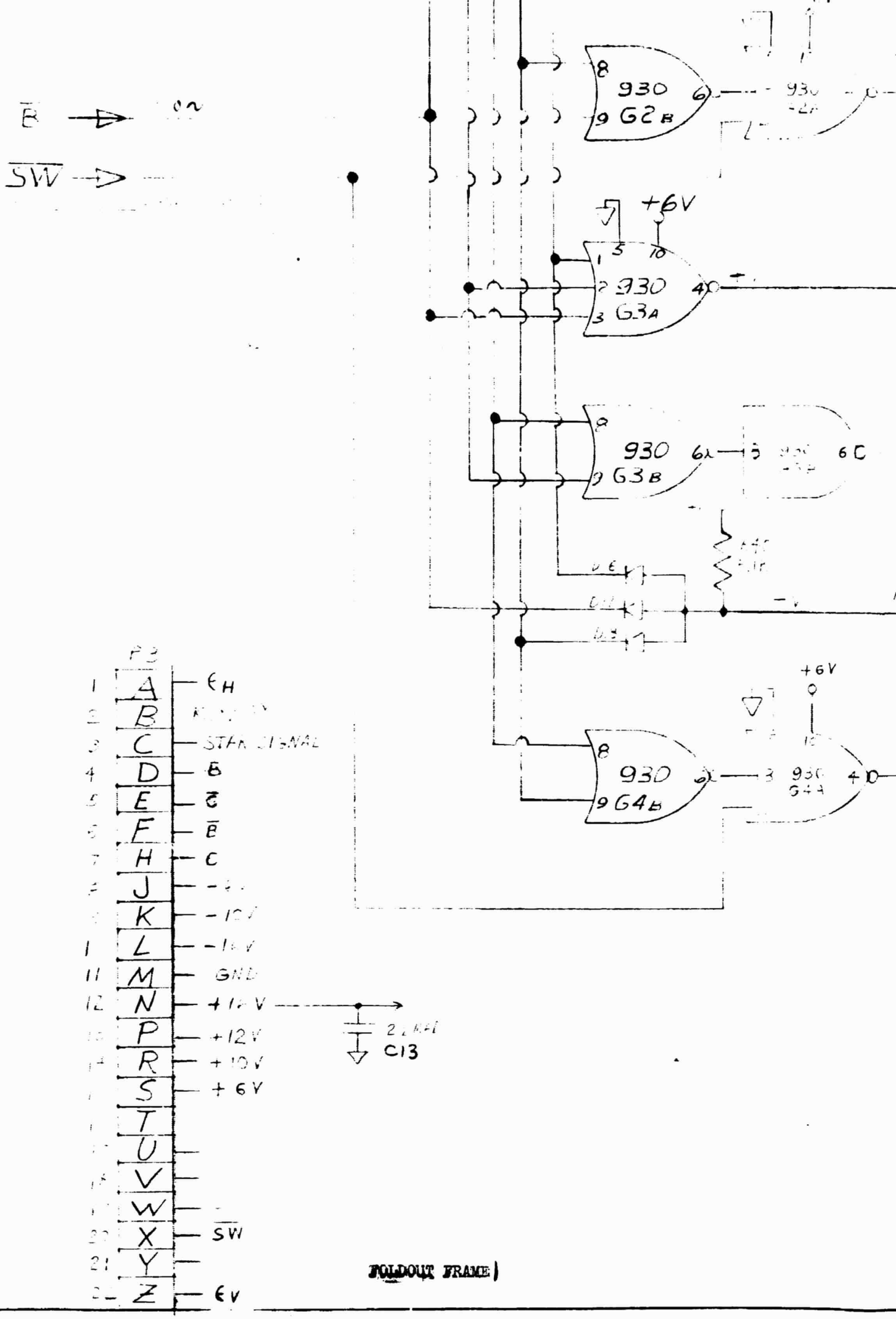

FF-1
-6
-18
R1 3K
R2 3K
R3 10K
R4 10K
C1 .15
C2 .15
C3 .001
R9 3.6K
R5 2.7K
R6 2.7K
2N3640
R7 51K
R8 51K
R10 33K
+12
AMPLIFIER #1
+65
+12
WHEEL MOTOR
1N1696
R23 25Ω 5WATT
R24 1K
R25 510
2N3646
2N3426
RCA 40256
R29 2K
R28 3.3K
R27 1.8K
R26 5.1K
AMP. INPU
DETECTOR
R48 6.8K
R49 15K
R50 15K
R51 6.8K
R53 3.6K
R54
R55 6.8K


FF-2
FF-3
-18
-6
R11
9.1K
R12
9.1K
R13-2.7K
R14
5.6K
R15
33K
C4-.15
2N3640
C5
.001
R16
3.6K
R17
33K
2N3640
C6
.33
R18
2.7K
R19
33K
R20
2.7K
+12
AMP. INPUT
-DET.
R30
9.1K
R31
6.2K
R32
33K
R33
9.1K
R34
9.1K
R35
6.2K
R36
33K
R37
9.1K
R38
9.1K
R39
33K
R40
6.2K
R41
1.8K
R42
5.1K
R47
3.3K
DETECTOR OR GATE
R56
32K
ALL

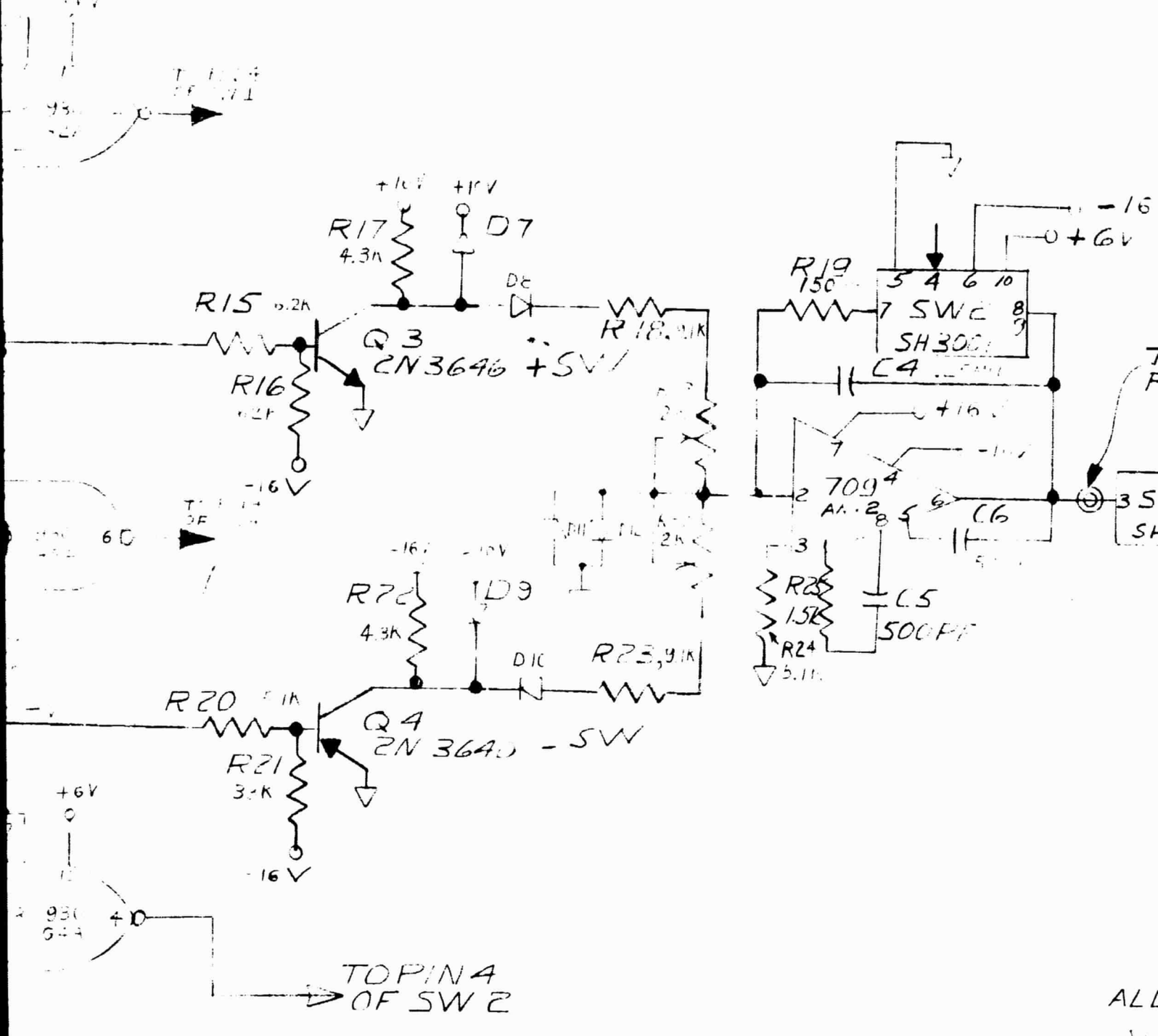
FOLDOUT FRAME 6



ALL UNLESS OTHERWISE SPECIFIED

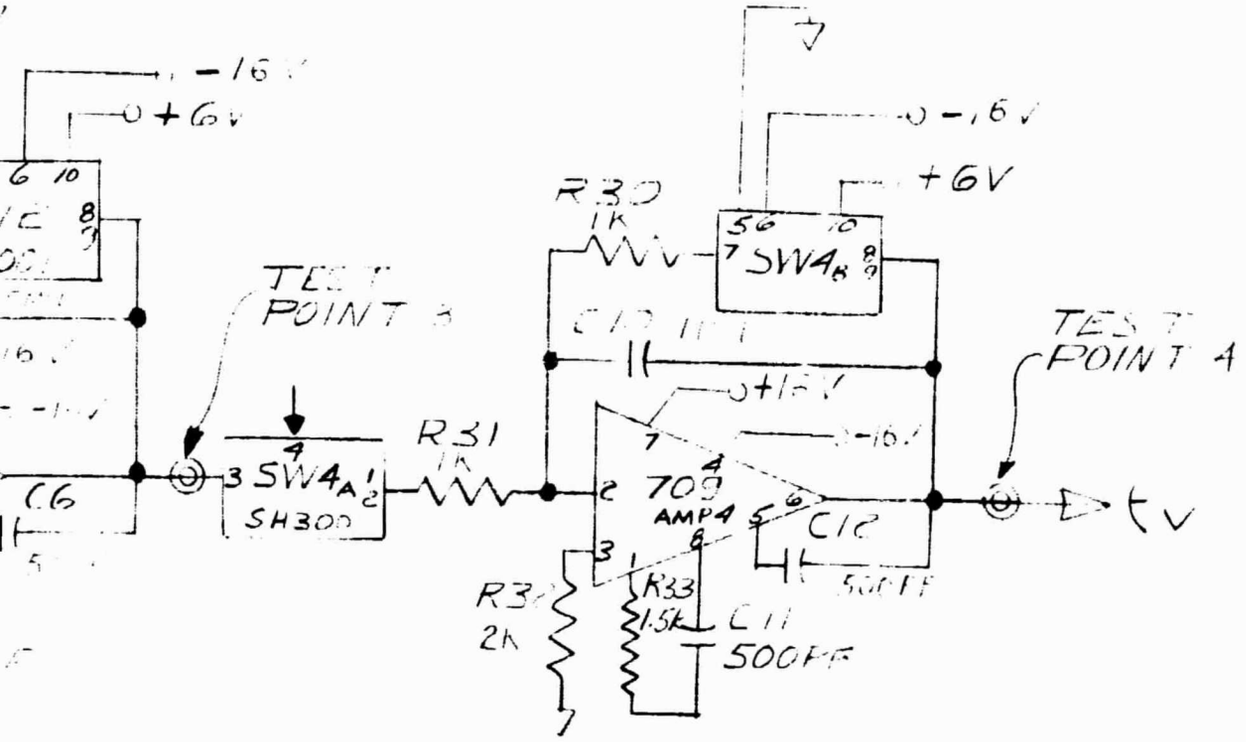


FOLDOUT FRAME 1



FOLDOUT FRAME 2

			SCALE	NON
			PROJ NO.	06
			DRAWN BY	J. P
C	TEST [illegible]	4-24	DATE	8-9
F	SIGNAL [illegible]	4-3-69	FOR ASSEMBLY	
A	MATCH [illegible]	3-25-68	MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	



ALL RESISTORS ¼ WATT 5%

ALL DIODES IN486F

GROUND SYMBOL

SUPPLY VOLTAGES BROUGHT OUT TO TEST POINTS

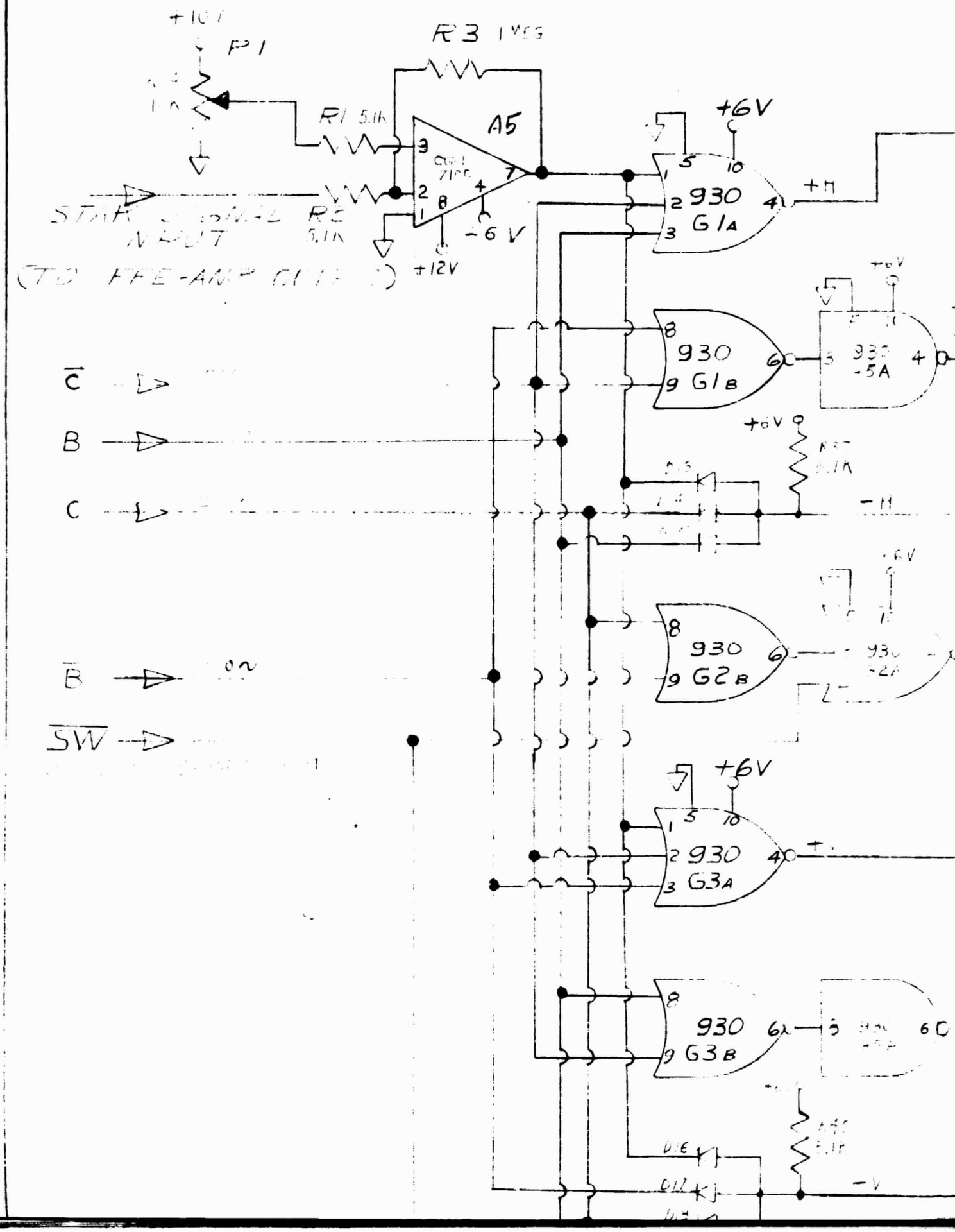
FOLDOUT FRAME 3

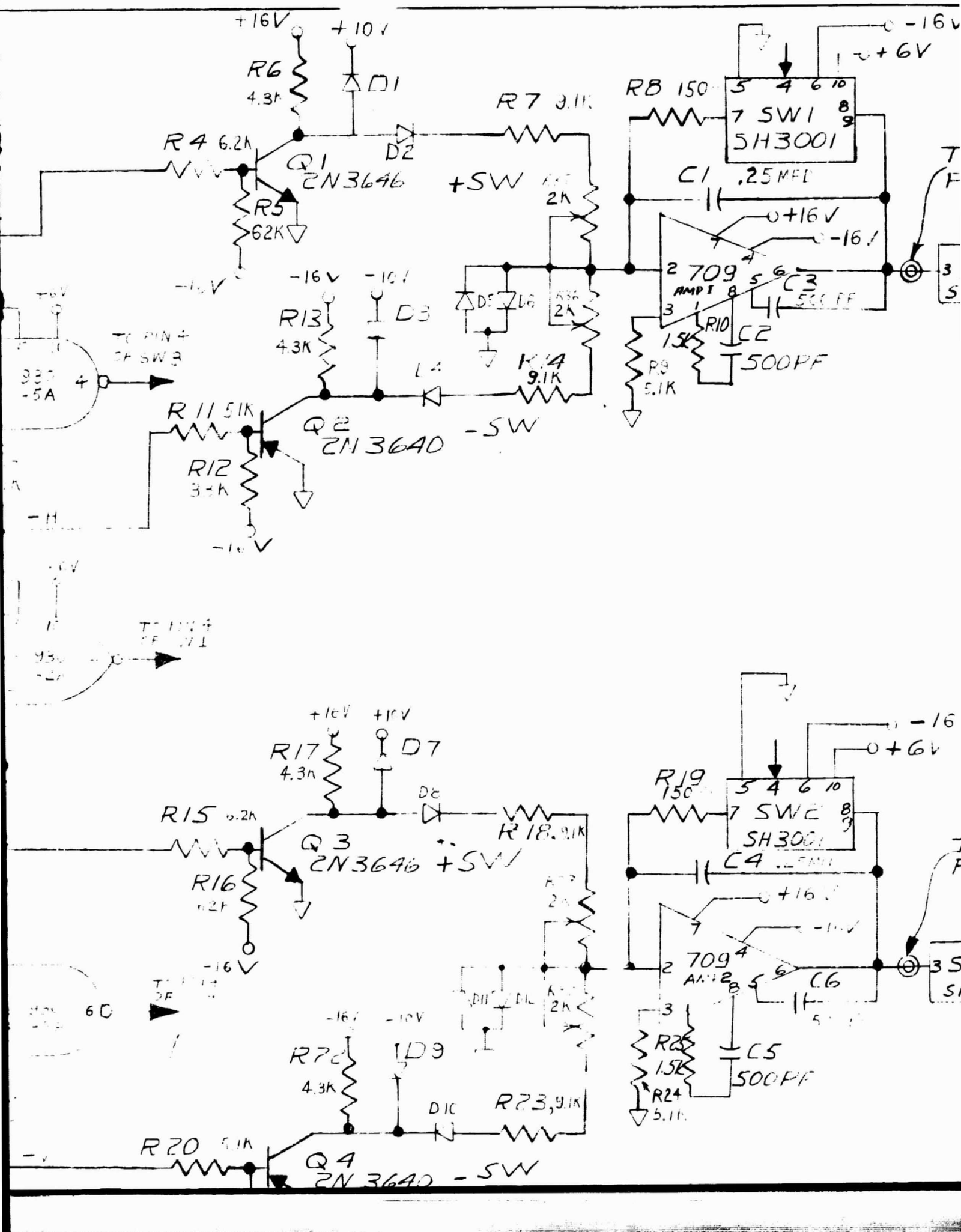
SCALE	NONE
PROJ NO.	06647
DRAWN BY	J. POUSAK
DATE	8-9-66
FOR ASSEMBLY	
MATERIAL	
WEIGHT CAL. ACT.	

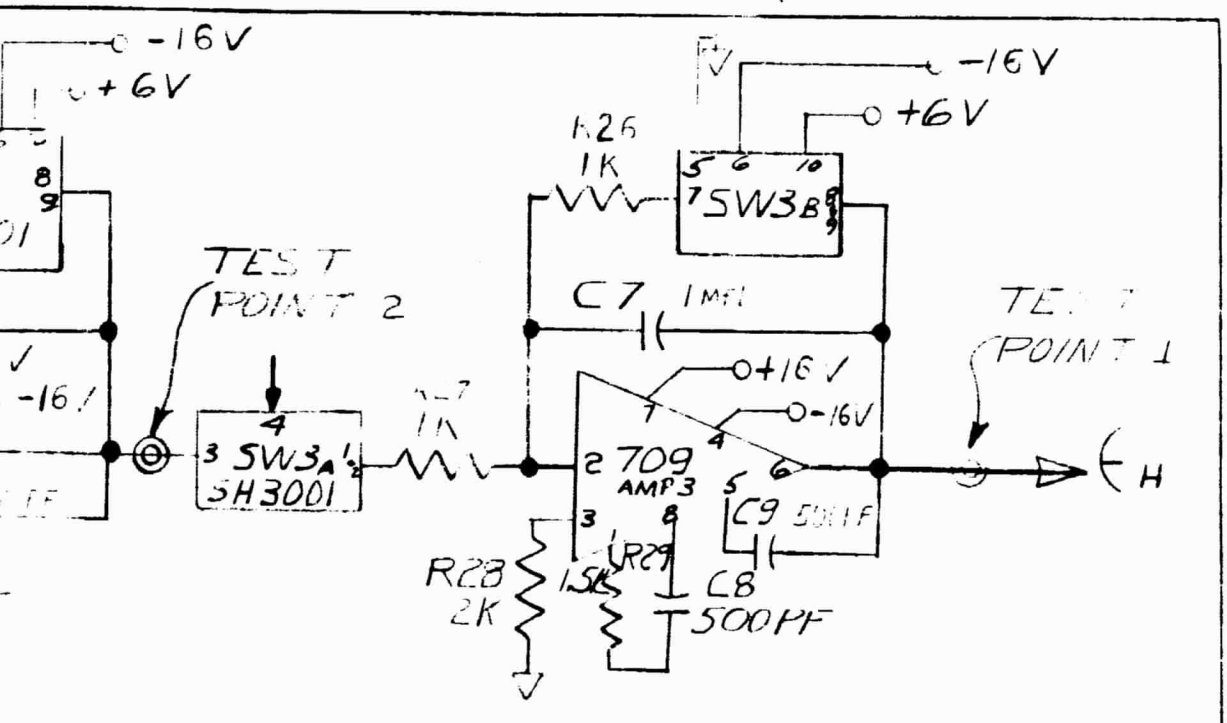
HIGH ALTITUDE ENGINEERING LABORATORY
UNIVERSITY OF MICHIGAN
DEPARTMENT OF AERO. AND ASTRO. ENGINEERING
ANN ARBOR MICHIGAN

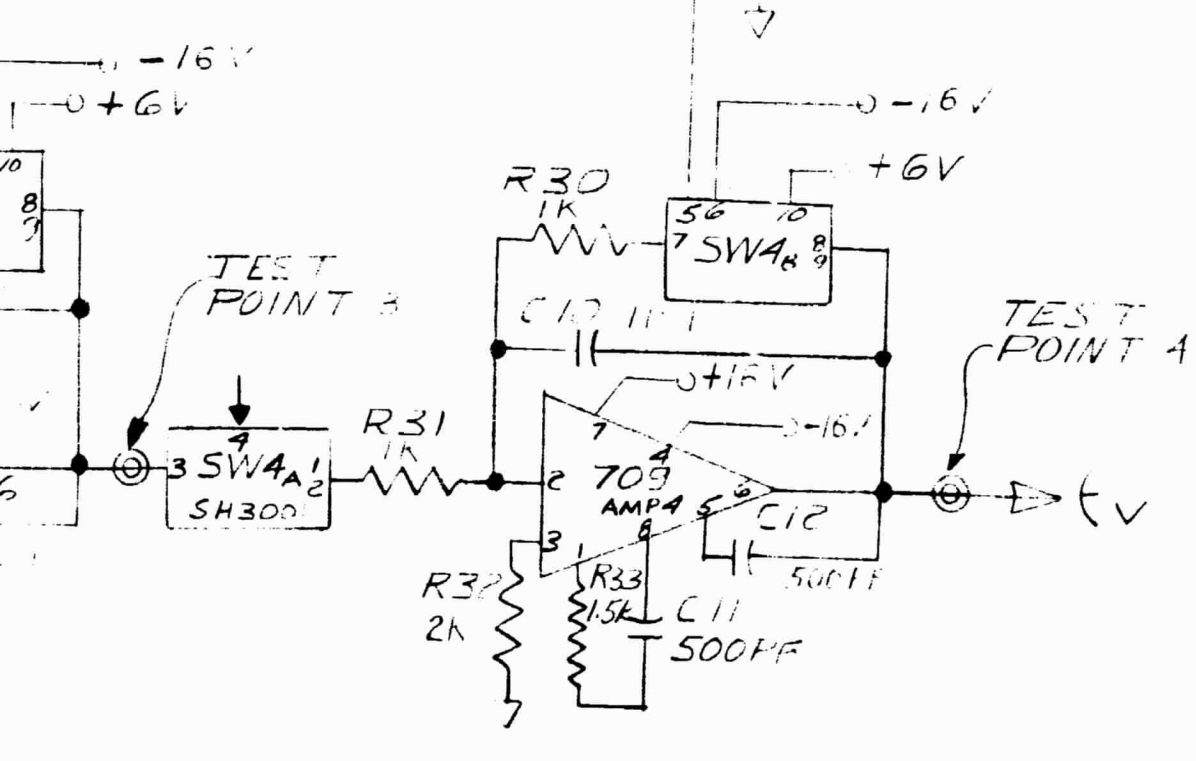
NAME
ATWILL DEMODULATOR

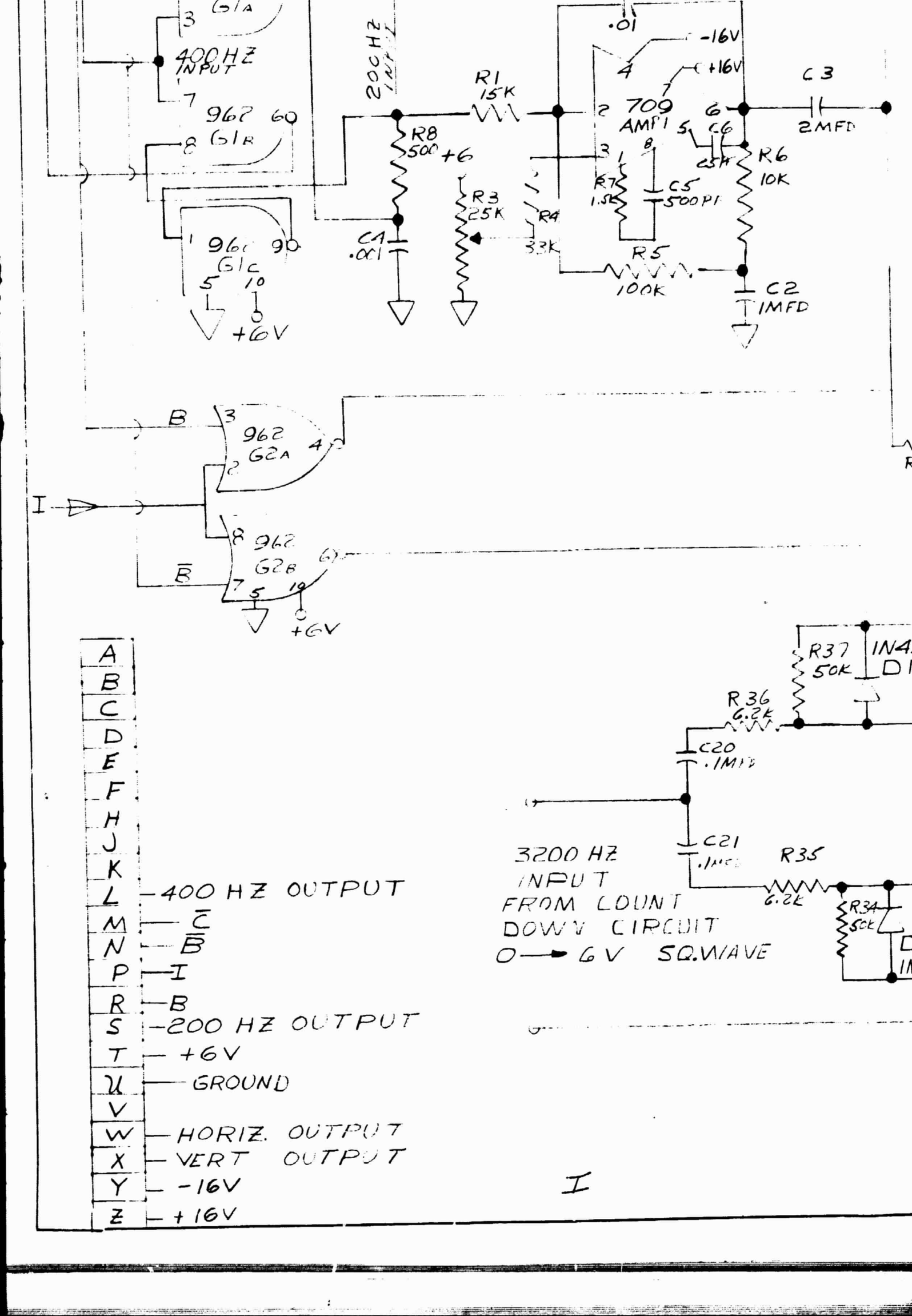
DRAWING NO. H3-52003

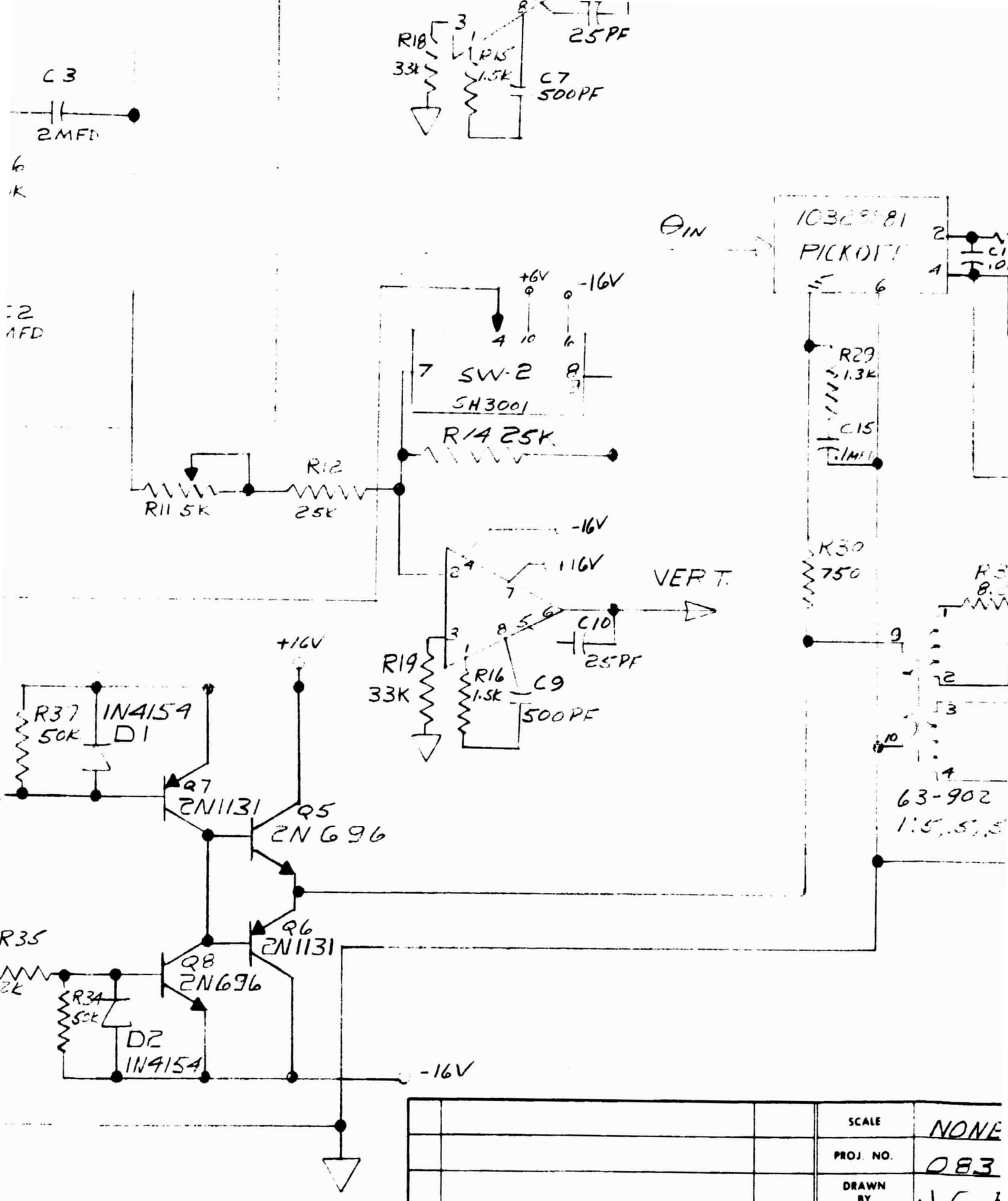

+10 V
P1
1K
R3 1MEG
R1 5.1K
A5
7106
-6 V
+12V
+6V
930
G1A
+M
930
G1B
-5A
+6V
-M
C
B
C
B
SW
930
G2B
+6V
930
G3A
930
G3B
-V


+16V
+10V
R6
4.3K
D1
R7 9.1K
R4 6.2K
Q1
2N3646
D2
+SW
R5
62K
-16V
R8 150
5 4 6 10
7 SW1 8
SH3001
C1 .25 MFD
+16V
-16V
2K
2 709 6
AMP 1 8
3 1
C3
R10
1.5K
C2
500PF
R9
5.1K
-16V
-10V
R13
4.3K
D3
D5
D6
2K
K14
9.1K
L4
R11 5.1K
Q2
2N3640
-SW
R12
3.3K
-16V
+16V
+10V
R17
4.3K
D7
D8
R15 6.2K
R18 9.1K
Q3
2N3646
+SW
R16
6.2K
-16V
R19
150
5 4 6 10
7 SW2 8
SH3001
C4 .25 MFD
+16V
-10V
2 709 6
AMP 2 8
3
C6
R25
1.5K
R24
5.1K
C5
500PF
-16V
-10V
R22
4.3K
D9
D10
R23 9.1K
R20 5.1K
Q4
2N3640
-SW


-16V
+6V
R26
1K
SW3B
TEST POINT 2
C7 1MFD
TEST POINT 1
+16V
-16V
SW3A 1/2
SH3001
1K
709
AMP3
C9 500PF
R28
2K
R29
1.5K
C8
500PF
H

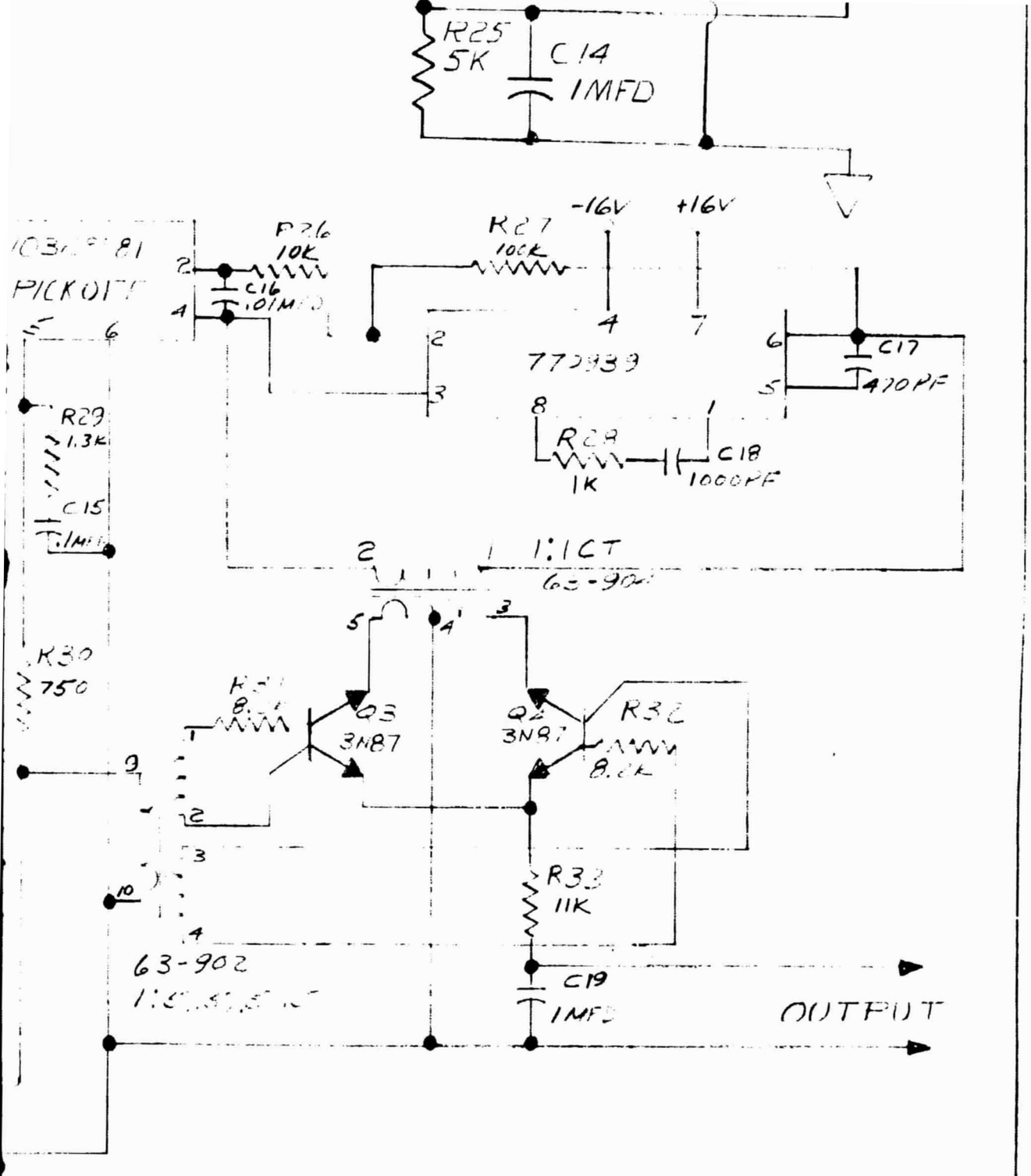

-16V
+6V
R30
1K
SW4B
TEST POINT 3
C10 1MFD
TEST POINT 4
+16V
-16V
SW4A 1/2
SH3001
R31
1K
709
AMP4
C12
500PF
R32
2K
R33
1.5K
C11
500PF
V


400 HZ INPUT
962 G1A
962 G1B
962 G1C
200 HZ
R1 15K
R8 500
+6
R3 25K
R4 33K
C4 .001
R5 100K
709 AMP
.01
-16V
+16V
C3 2MFD
C6 .05
R6 10K
R7 1.5K
C5 500 PF
C2 1MFD
+6V
B
962 G2A
I
962 G2B
$\bar{B}$
+6V
R37 50K
R36 6.2K
C20 .1MFD
C21 .1MFD
R35 6.2K
R34 5CK
3200 HZ INPUT FROM COUNT DOWN CIRCUIT
0 → 6V SQ.WAVE
A
B
C
D
E
F
H
J
K
L — 400 HZ OUTPUT
M — $\bar{C}$
N — $\bar{B}$
P — I
R — B
S — 200 HZ OUTPUT
T — +6V
U — GROUND
V
W — HORIZ. OUTPUT
X — VERT OUTPUT
Y — -16V
Z — +16V
I



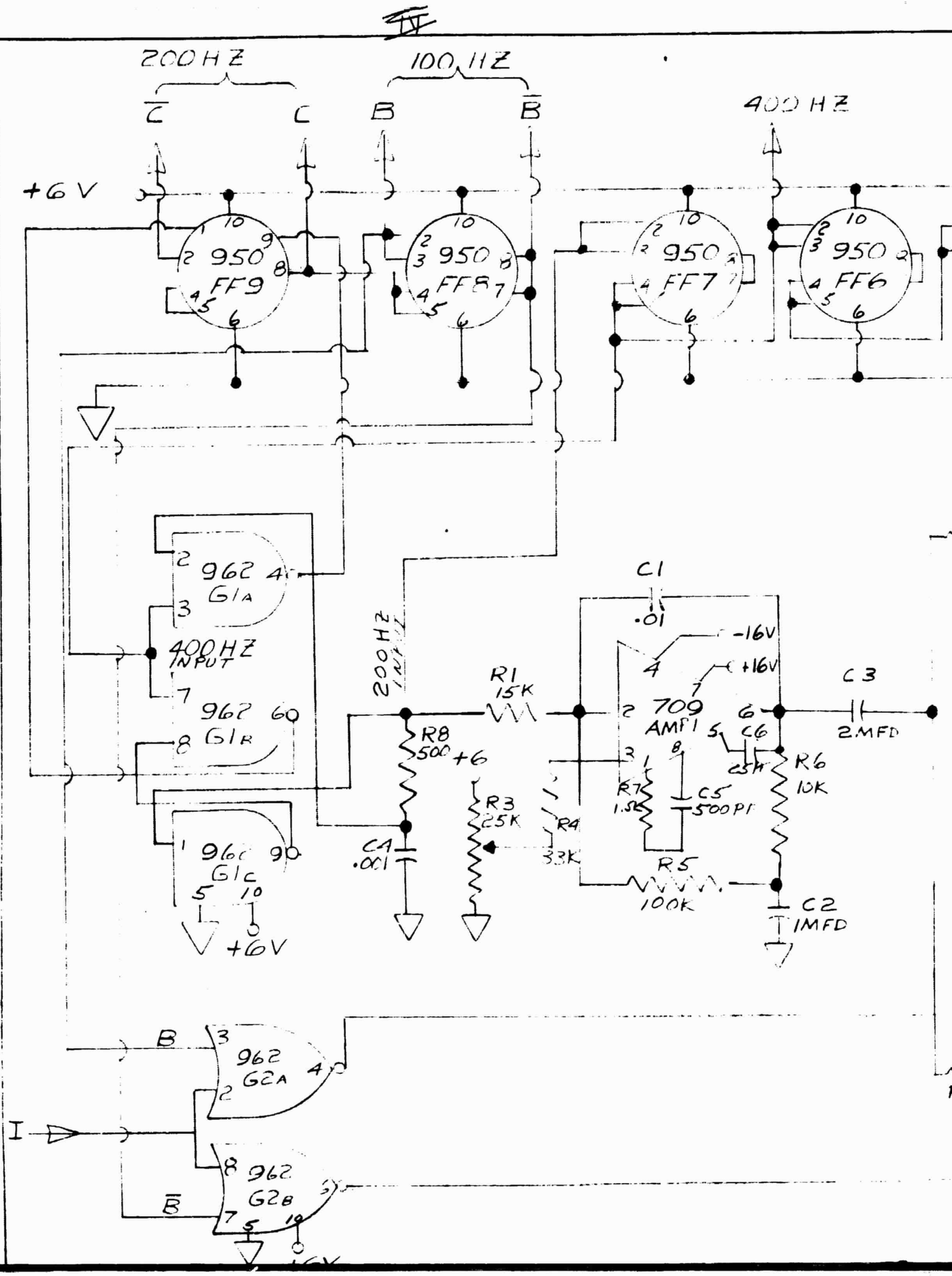
			SCALE	NONE
			PROJ. NO.	083
			DRAWN BY	J.C.
			DATE	10-6
			FOR ASSEMBLY	
			MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

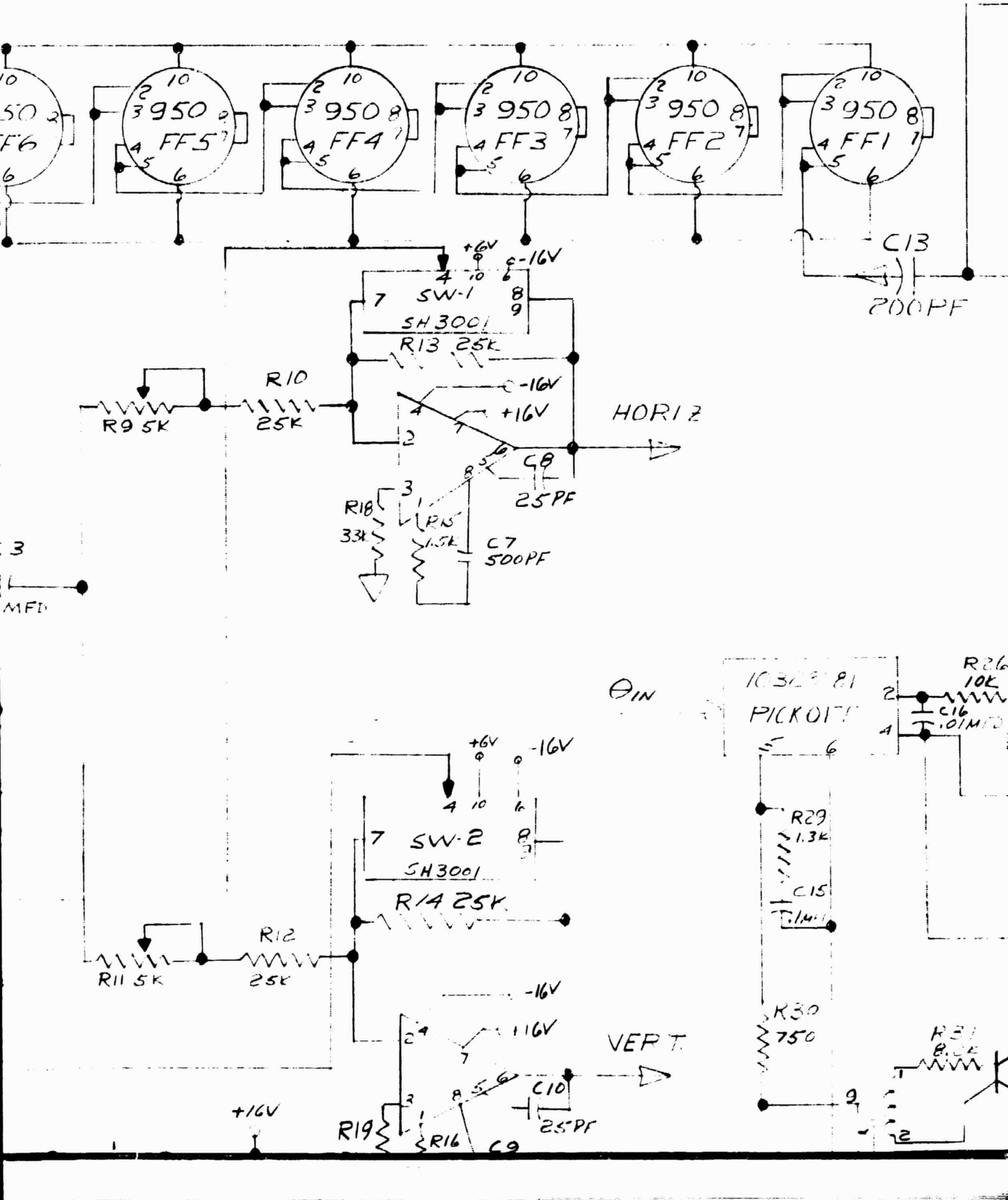
II

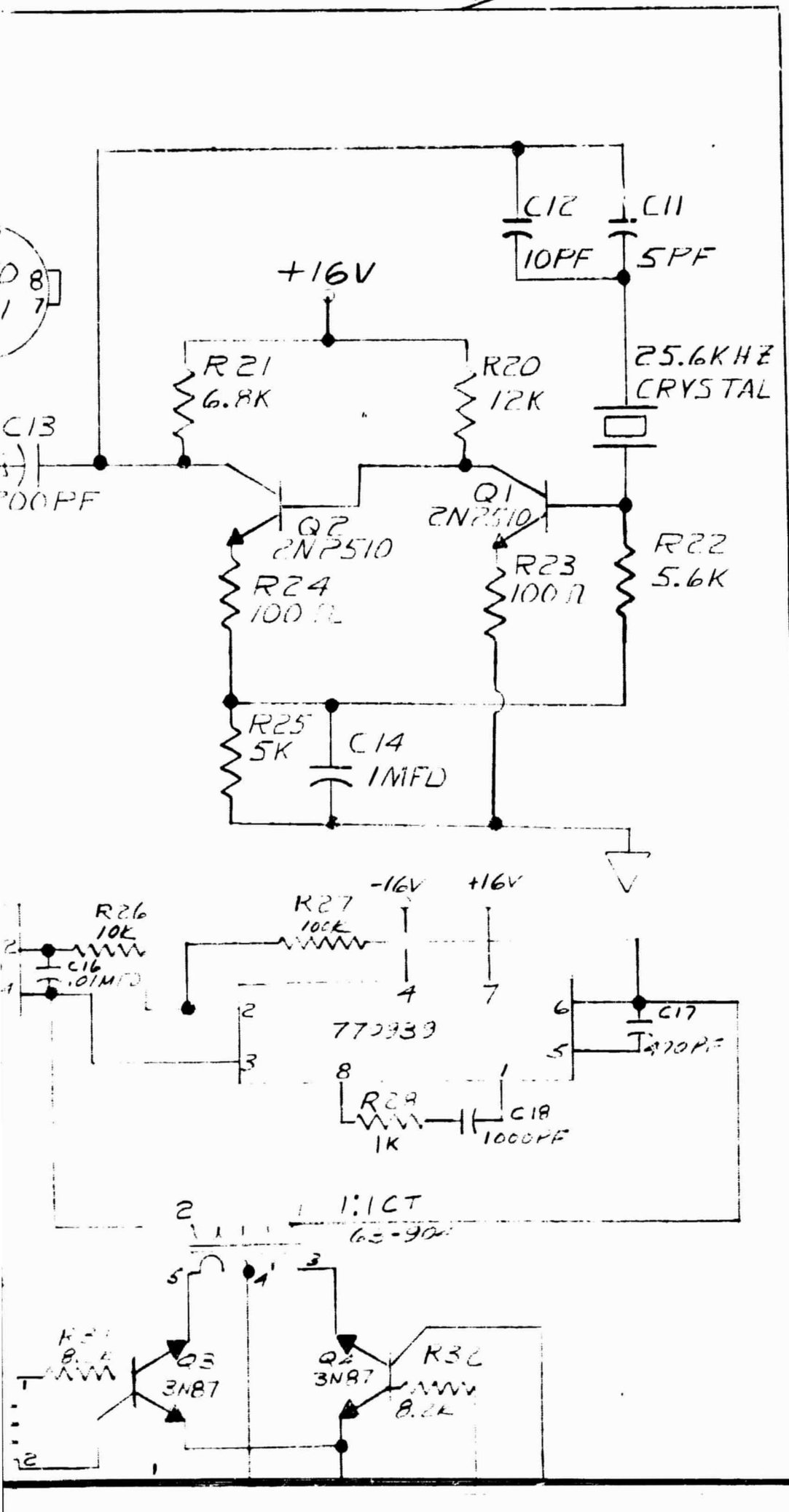


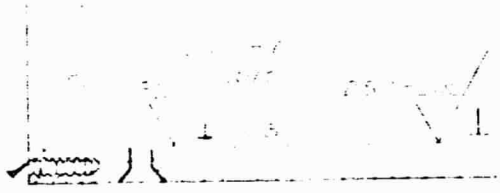
SCALE	NONE	HIGH ALTITUDE ENGINEERING LABORATORY UNIVERSITY OF MICHIGAN DEPARTMENT OF AERO. AND ASTRO. ENGINEERING ANN ARBOR MICHIGAN
PROJ. NO.	08370	
DRAWN BY	J.C. POUSAK	
DATE	10-6-66	NAME ATWILL SCAN GENERATOR + TORQUE COMPENSATOR
FOR ASSEMBLY		
MATERIAL		DRAWING NO. H3-52004
WEIGHT CAL ACT.		

III


200 HZ
100 HZ
400 HZ
C
C
B
B
+6V
950 FF9
950 FF8
950 FF7
950 FF6
962 G1A
962 G1B
962 G1C
400 HZ INPUT
200 HZ INPUT
R1 15K
R8 500
+6
R3 25K
R4 3.3K
C4 .001
C1 .01
-16V
+16V
709 AMP1
C3 2 MFD
C6 .25M
R6 10K
R7 1.5K
C5 500 PF
R5 100K
C2 1 MFD
962 G2A
962 G2B
B
I
B
+6V
-16V


950 FF5
950 FF4
950 FF3
950 FF2
950 FF1
C13
200PF
+6V
-16V
SW-1
SH3001
R13 25K
R10
R9 5K
25K
-16V
+16V
HORIZ
C8
25PF
R18
33K
R17
1.5K
C7
500PF
MFD
θIN
PICKOFF
R26
10K
C16
.01MFD
+6V
-16V
SW-2
SH3001
R14 25K
R12
R11 5K
25K
-16V
+16V
VERT
C10
25PF
R29
1.3K
C15
.1MFD
R30
750
+16V
R19
R16
C9


C12
10PF
C11
5PF
+16V
R21
6.8K
R20
12K
25.6KHZ
CRYSTAL
C13
Q1
2N2510
Q2
2N2510
R24
100Ω
R23
100Ω
R22
5.6K
R25
5K
C14
1MFD
-16V
+16V
R26
10K
C16
.01MFD
R27
100K
4
7
2
3
77933
6
5
C17
8
1
R28
1K
C18
1000PF
2
1:1CT
5
1
3
Q3
3N87
Q4
3N87
R30
8.2K



SECTION A-A

1. FROM CROSS.
2. FINISH FLAT SLOPE AS SHOWN. COATING AS SPECIFIED ON SHEET
3. DRILL AND EPOXY #4 BAR 12 INCHES.
4. MATCH VALLEY GUTTER ON N.D.
5. DRILL AND EPOXY DOWEL INTO EXISTING CONCRETE SURFACE.
6. #4 BAR @ 12" O.C. UNLESS OTHERWISE SHOWN.
7. FOR ALL CONSTRUCTION JOINT DETAILS SEE SHEET
8. SEE NOTE 4 ON HB-5600G (PAST BEFORE DRILLING.

I

			SCALE	ONE - HAL
			PROJ NO.	01114
			DRAWN BY	F 3
C	H [illegible]	3 [illegible]	DATE	1-30-6
B	[illegible]	[illegible]	FOR ASSEMBLY	
A	WA [illegible]	[illegible]	MATERIAL	AZ-31
LET	CHANGE	DATE	WEIGHT CAL. ACT.	

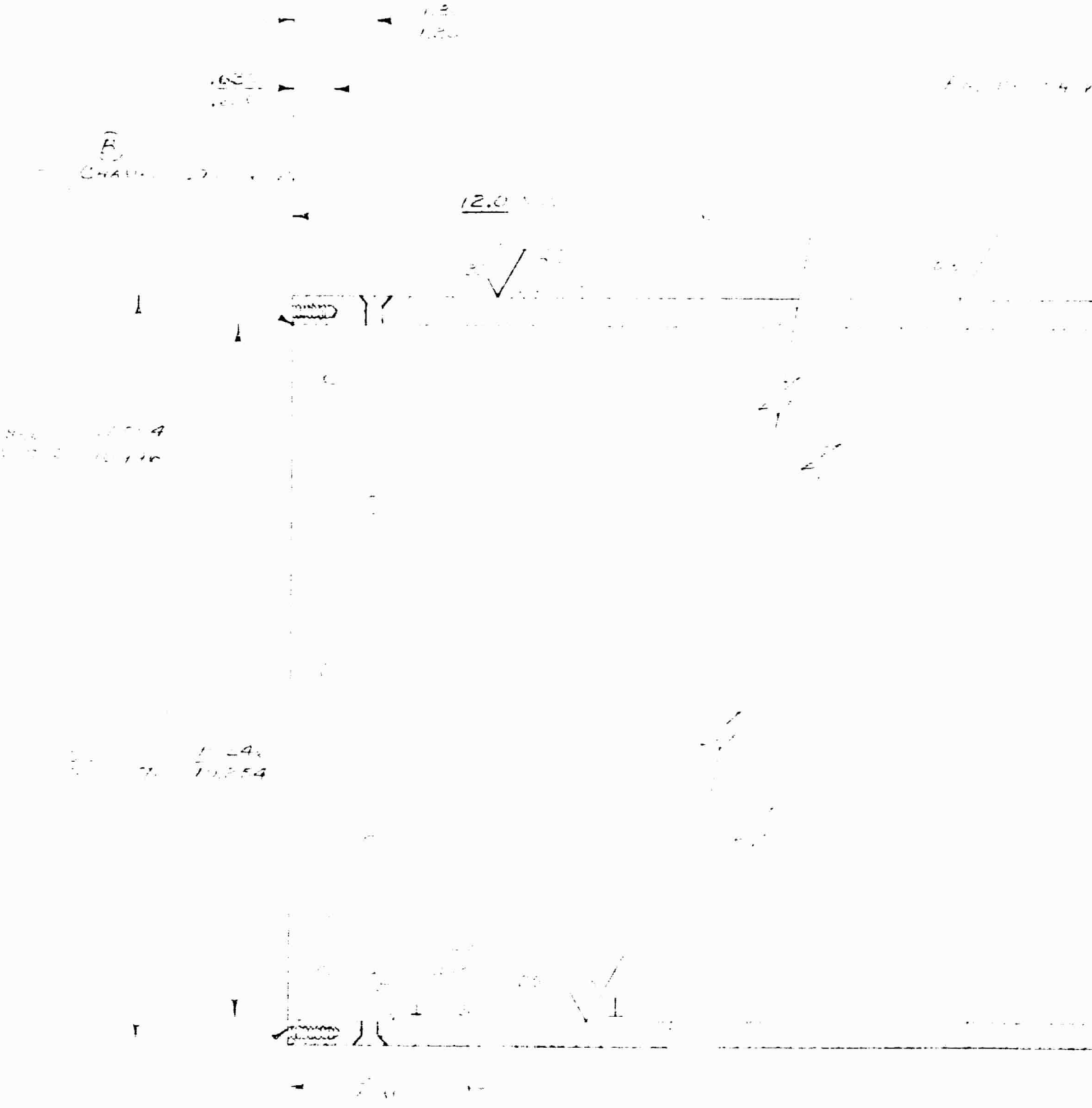
II

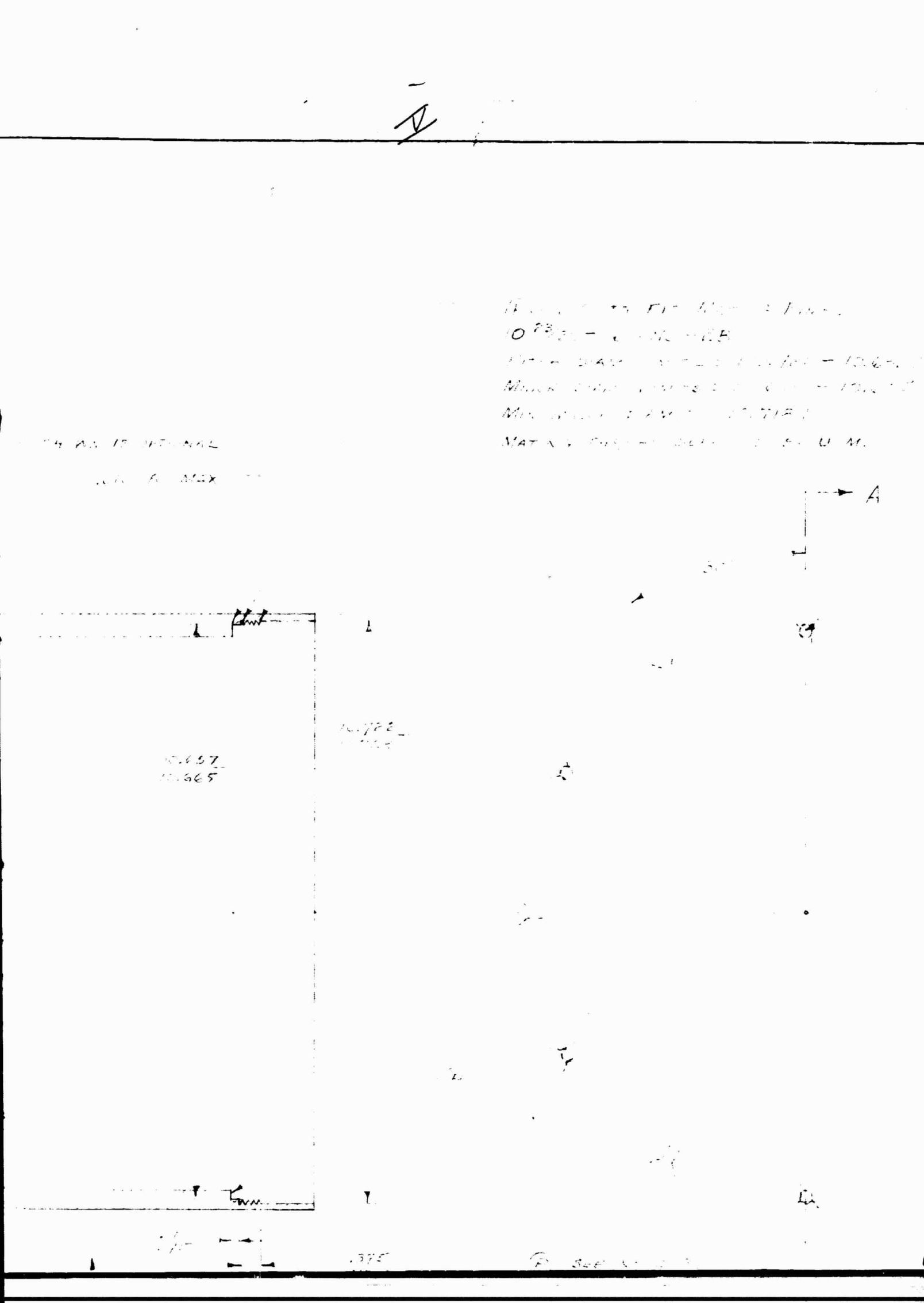
A

	HIGH ALTITUDE ENGINEERING LABORATORY **UNIVERSITY OF MICHIGAN** ***DEPARTMENT OF AERO. AND ASTRO. ENGINEERING*** **ANN ARBOR MICHIGAN**
	NAME TEST-DATA SCAN
	DRAWING NO. HS-52305

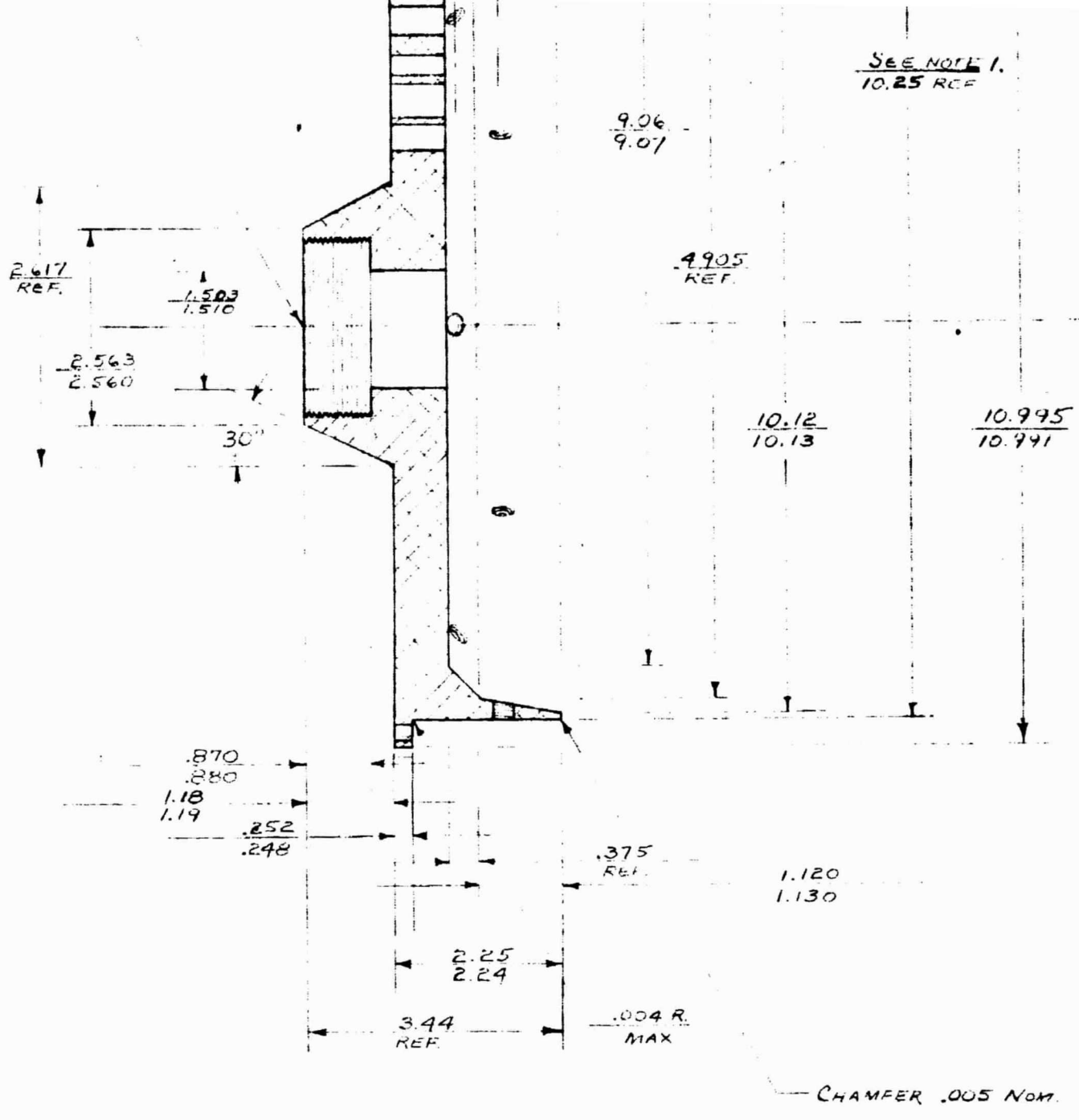
III

IV




A
.375

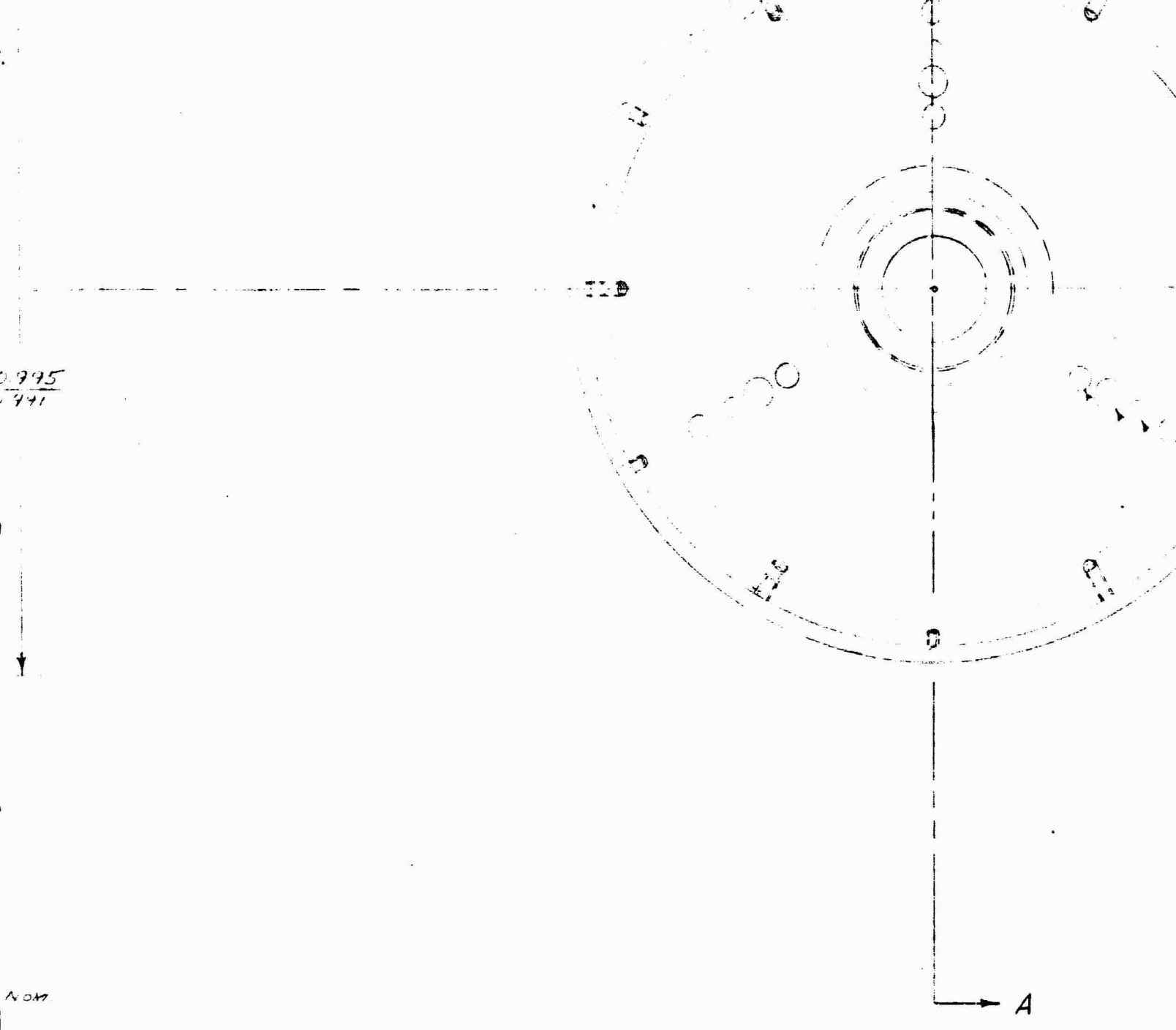
VI



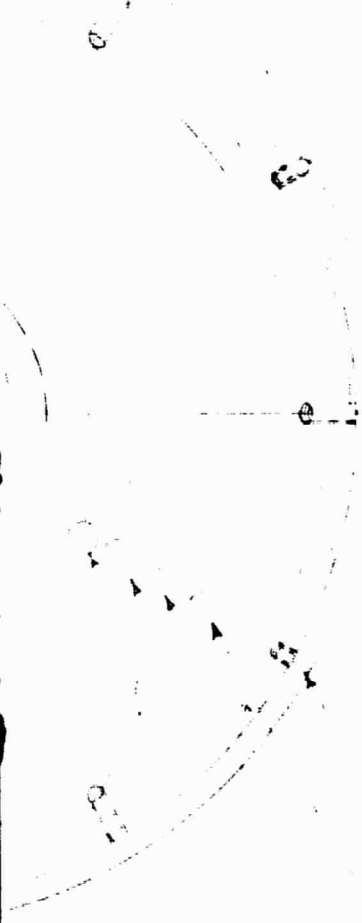
SECTION A-A

NOTES:

1. DIM. TO BE .001 LESS THAN MATING PART. (H3-52005) MATING PART DIM. 10.246 - 10.254.
2. BREAK EDGES.
3. FINISH IN FLAT BLACK ANODIZE. COATING NOT TO EXCEED .0004.
4. ASSEMBLE TO H3-52005 (TUBE) FOR DRILLING ON 10.625 DIA. APEX TAPPING HOLES IN H3-52005 ON 10.625 DIA. ASSEMBLE WITH (6) 10-24 SCREWS FOR RADIAL HOLE LOCATION & PILOT DRILLING. SCRATCH FIDUCIAL MARK.



			SCALE	ONE-M
			PROJ. NO.	01114
			DRAWN BY	F 3
			DATE	3-13-68
			FOR ASSEMBLY	
A	NOTE 4. ADDED HOLES ADDED.	3-25-68	MATERIAL	AZ-31
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	



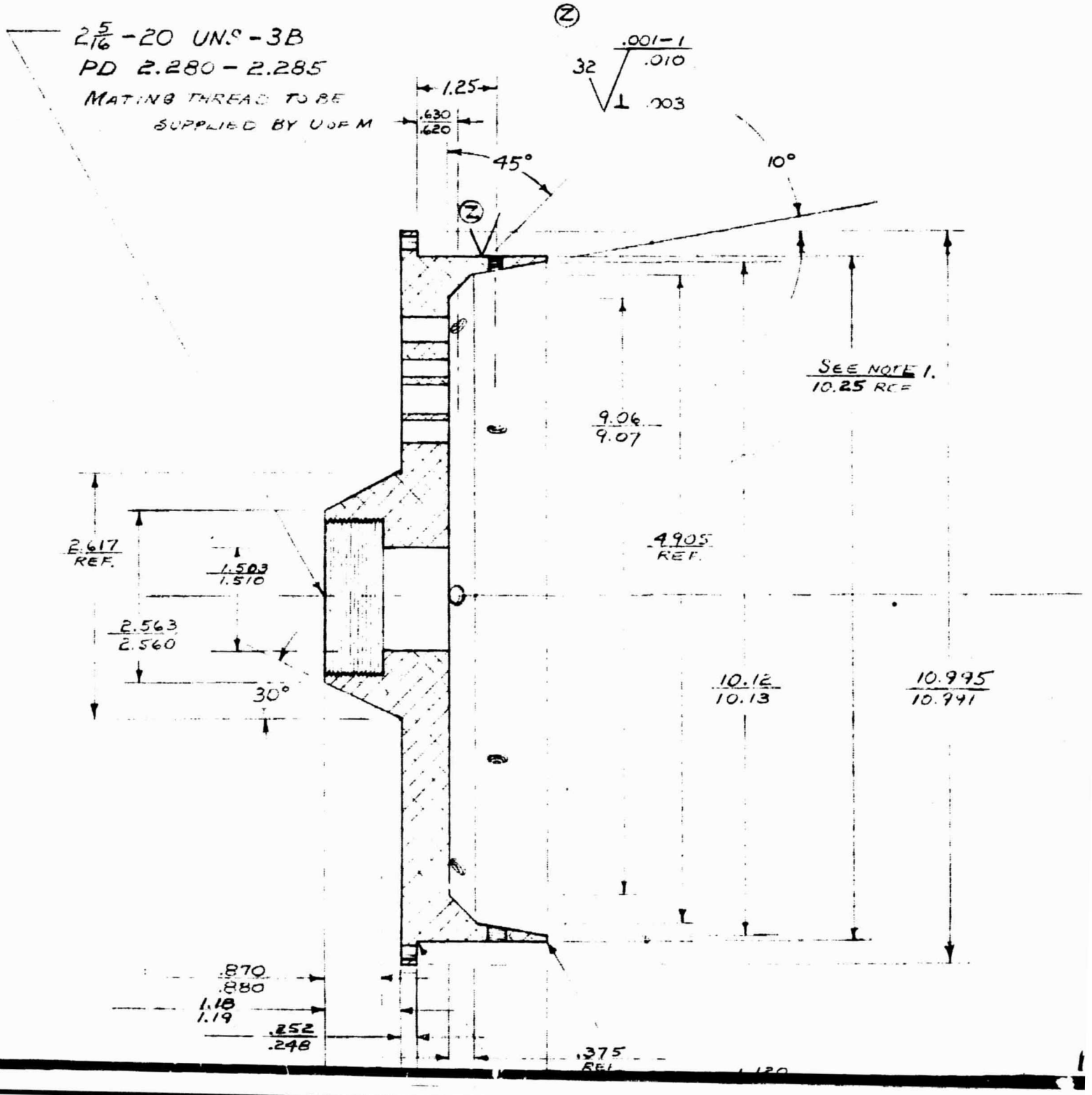
(A)

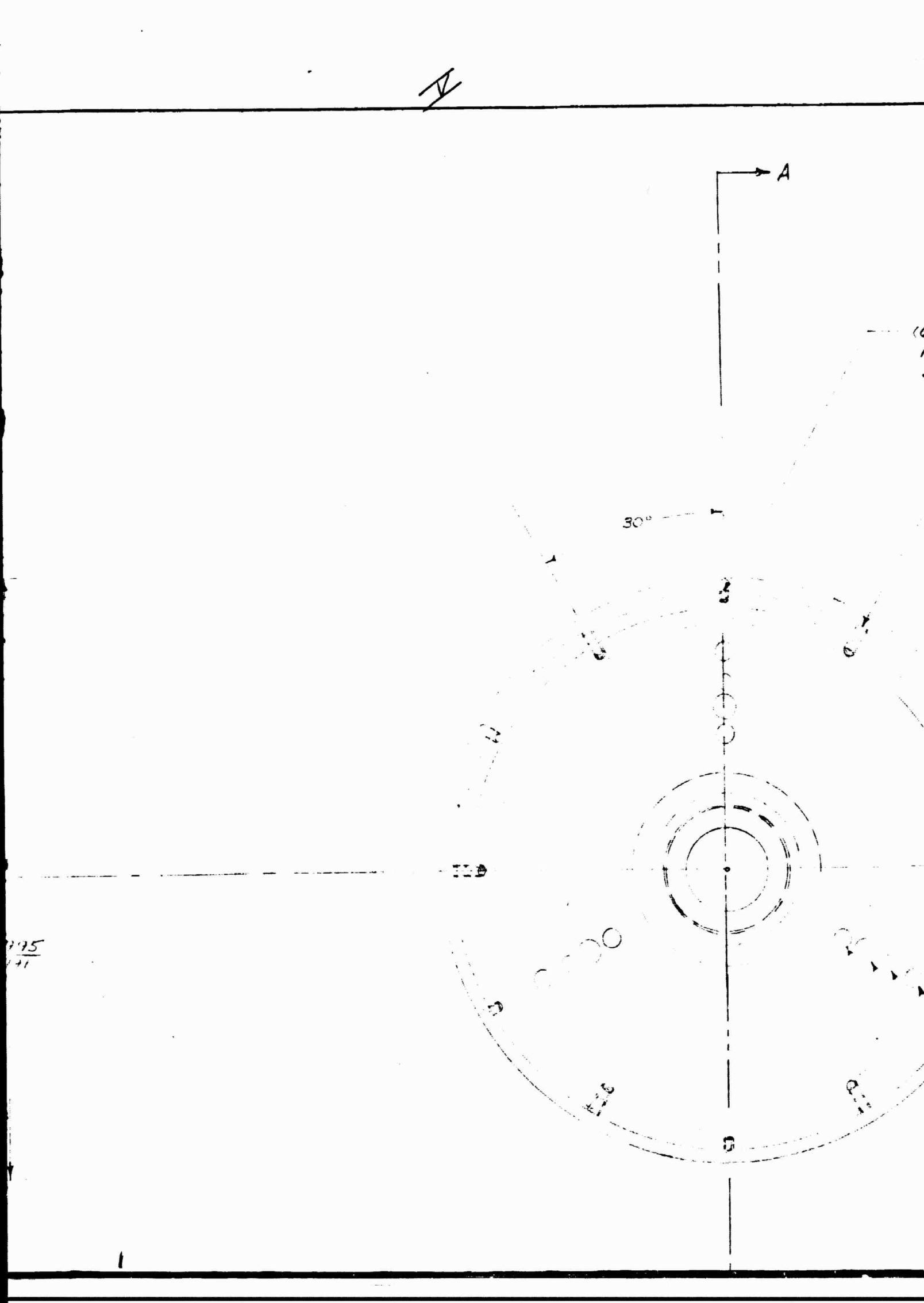
DRILL THRU (6) HOLES EQUALLY SPACED ON 10.625 ± .003 B.C.
#A DRILL (.194)

(5) HOLES 21/64 D. THRU 8.040 ± .003 B.C.
(3) HOLES 17/64 D. THRU 6.875 ± .005 B.C.
(3) HOLES "X" D. THRU 6.000 ± .005 B.C.
(3) HOLES 5/16 D. THRU 4.125 ± .003 B.C.
ALL EQUALLY SPACED
17/64 HOLES DIA. .265 - .271
REAMED HOLES.

ONE-HALF	HIGH ALTITUDE ENGINEERING LABORATORY UNIVERSITY OF MICHIGAN DEPARTMENT OF AERO. AND ASTRO. ENGINEERING ANN ARBOR MICHIGAN
01114	
F³	
3-13-68	NAME BASE-DATA SCOPE
AZ-31	DRAWING NO. H3-52006
	III

IV

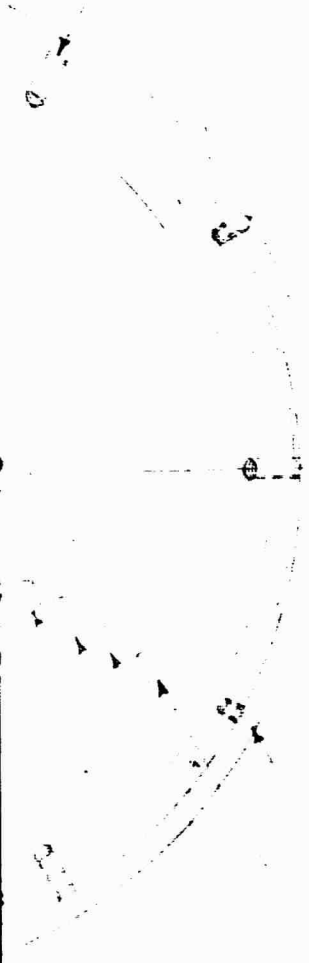

2 5/16 - 20 UNS - 3B
PD 2.280 - 2.285
MATING THREAD TO BE SUPPLIED BY USFM
(2)
.001 - 1
32
.010
⊥ .003
1.25
.630
.620
45°
10°
(2)
SEE NOTE 1.
10.25 REF
9.06
9.07
4.905
REF.
2.617
REF.
1.503
1.510
2.563
2.560
30°
10.12
10.13
10.995
10.991
.870
.880
1.18
1.19
.252
.248
.375
REF.


A
30°

VI

(6) HOLES EQUALLY SPACED ON RADII.
10-24 UNC-2B DRILL & TAP.
SEE NOTE 4.

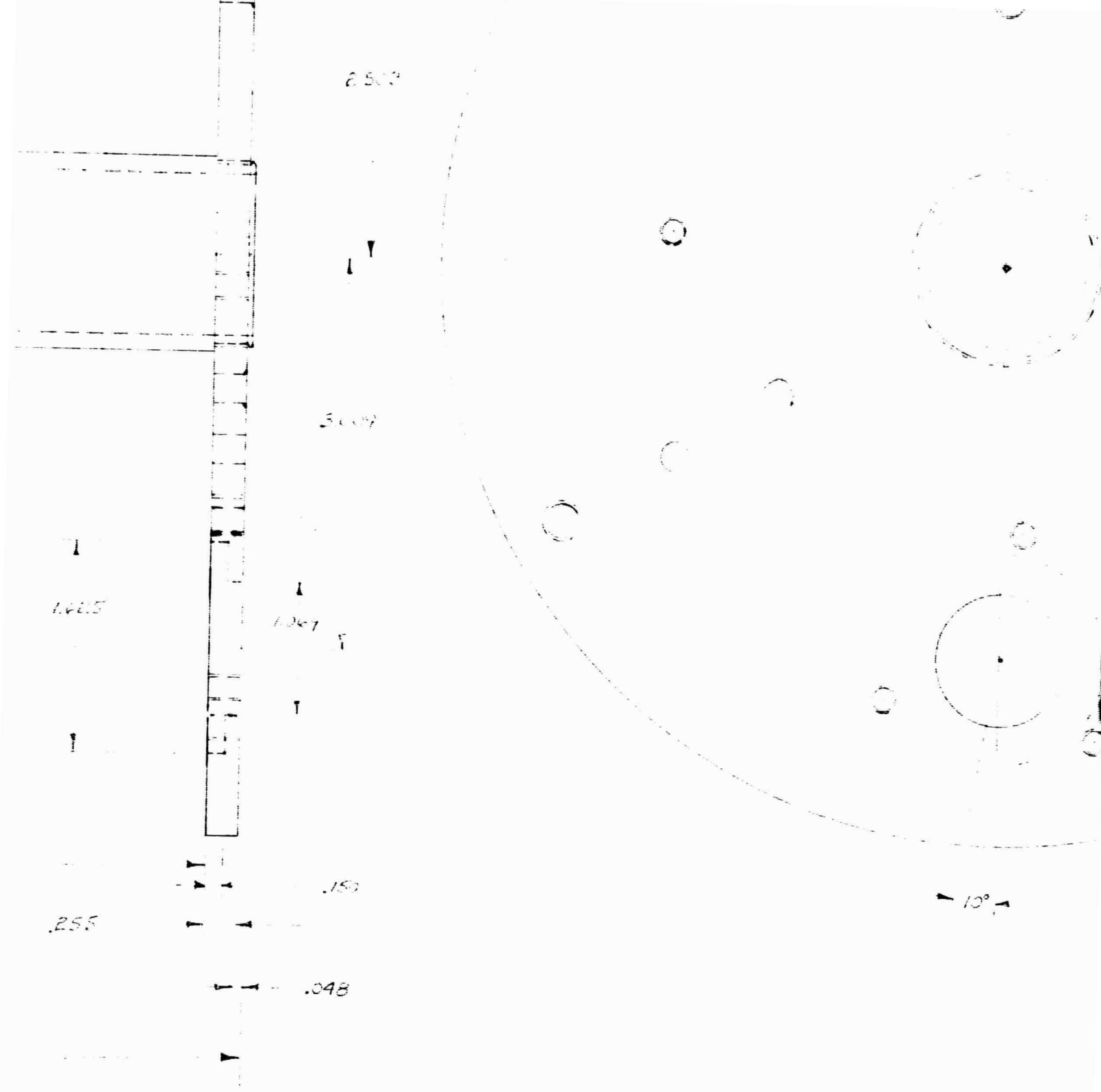
(6) HOLES EQUALLY SPACED ON RADII.
10-24 UNC-2B DRILL & TAP.
SEE NOTE 4.



(A)

DRILL THRU (6) HOLES EQUALLY
SPACED ON 10.625 ±.003 B.C.
#(A) DRILL (.194)

(5) HOLES 21/64 D. THRU 8.040 ±.003 B.C.
(3) HOLES 17/64 D. THRU 6.875 ±.005 B.C.
(3) HOLES "X" D. THRU 6.000 ±.005 B.C.
(3) HOLES 5/16 D. THRU 4.165 ±.003 B.C.

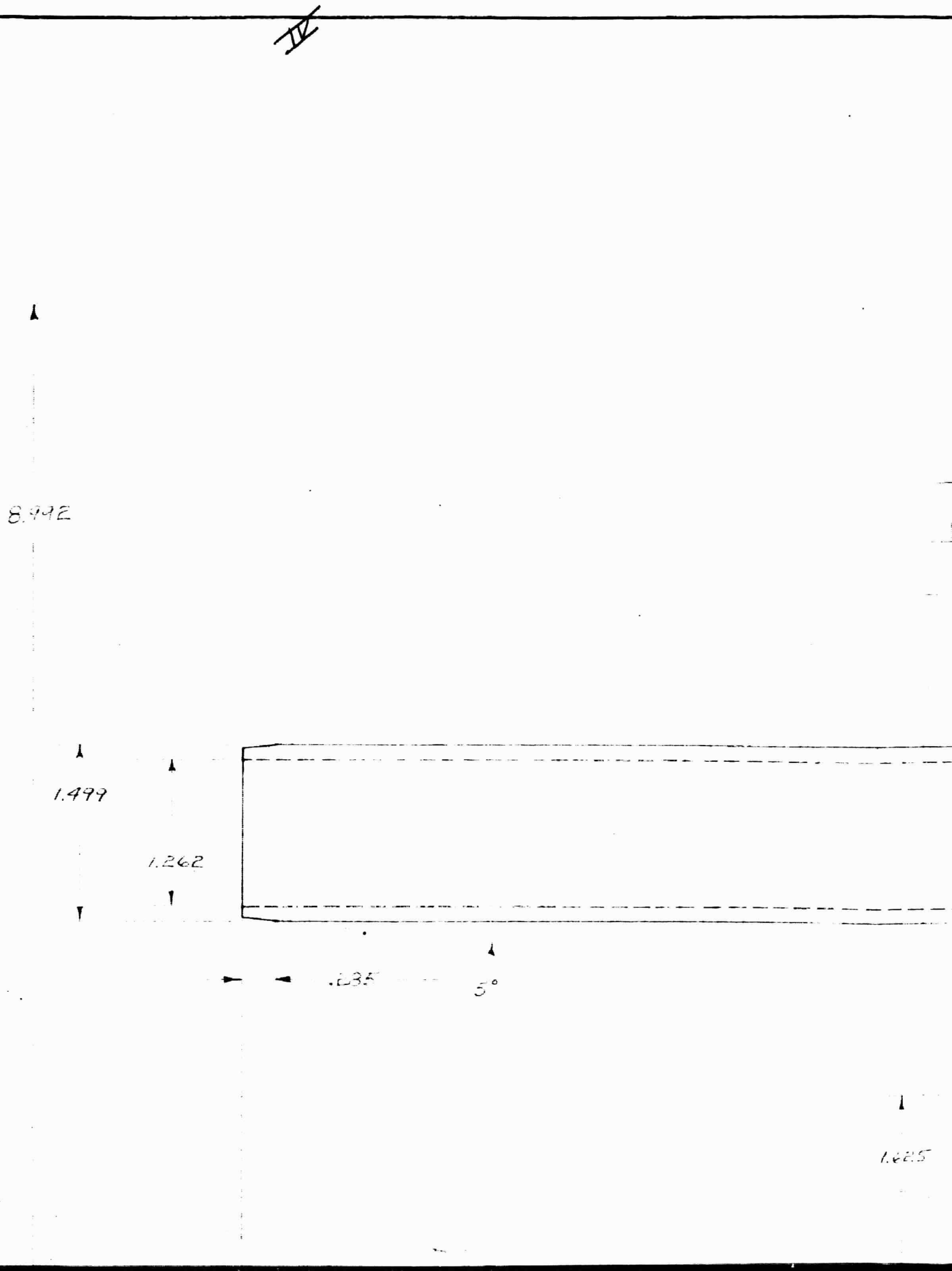


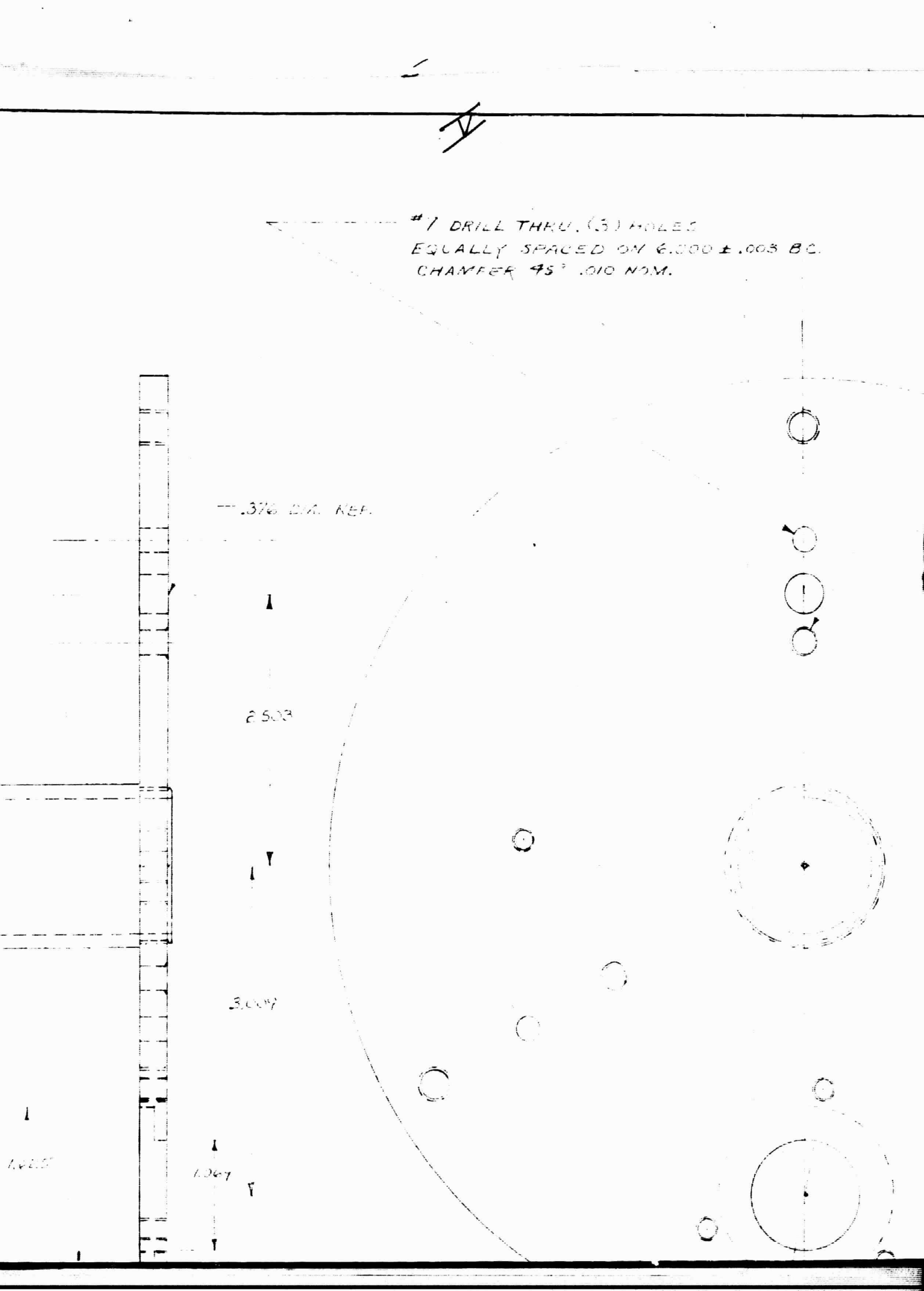
			SCALE	FULL
			PROJ. NO.	01114
			DRAWN BY	F3
			DATE	3-20-68
			FOR ASSEMBLY	
			MATERIAL	AL. ALLO
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

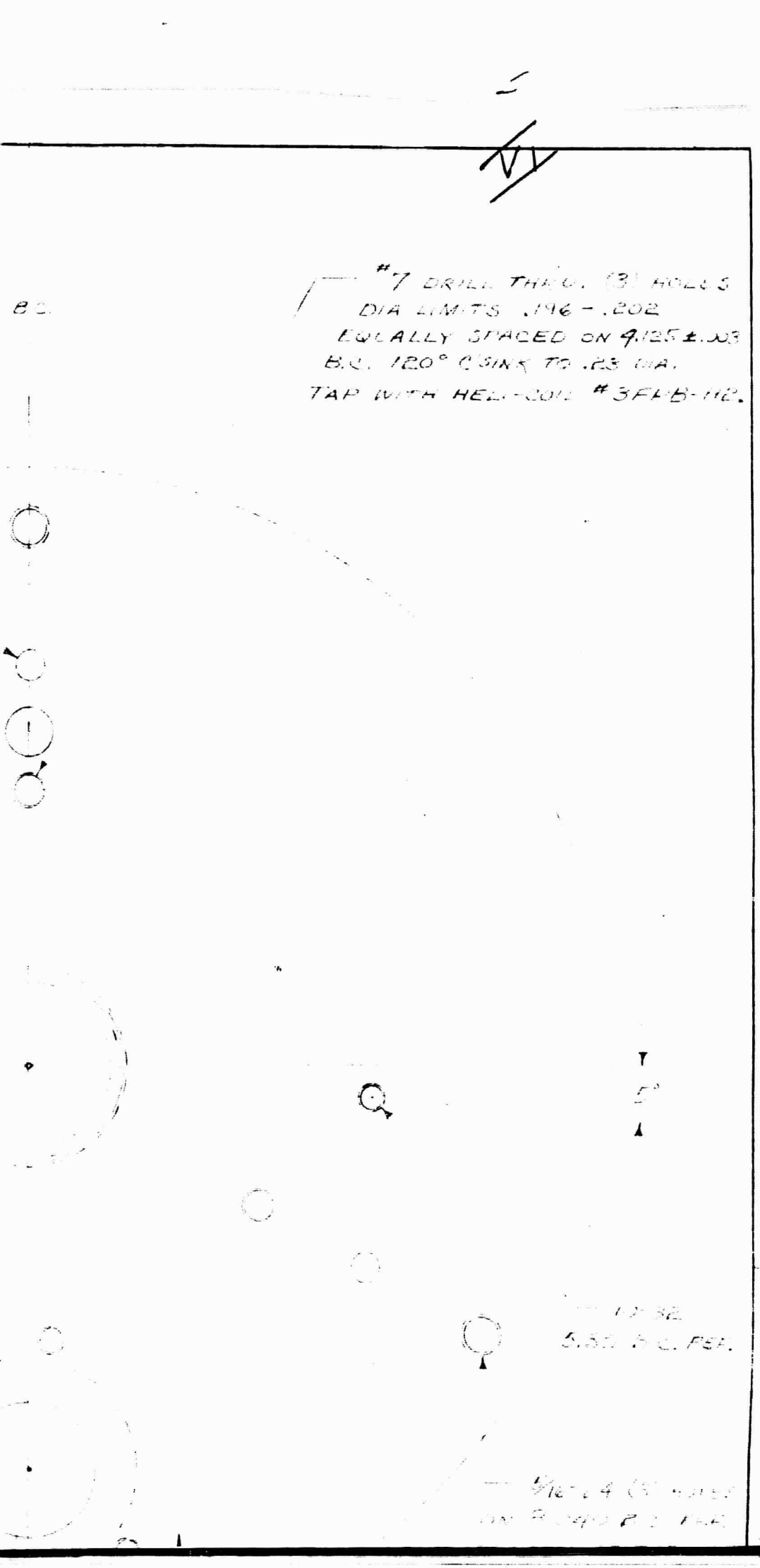
II

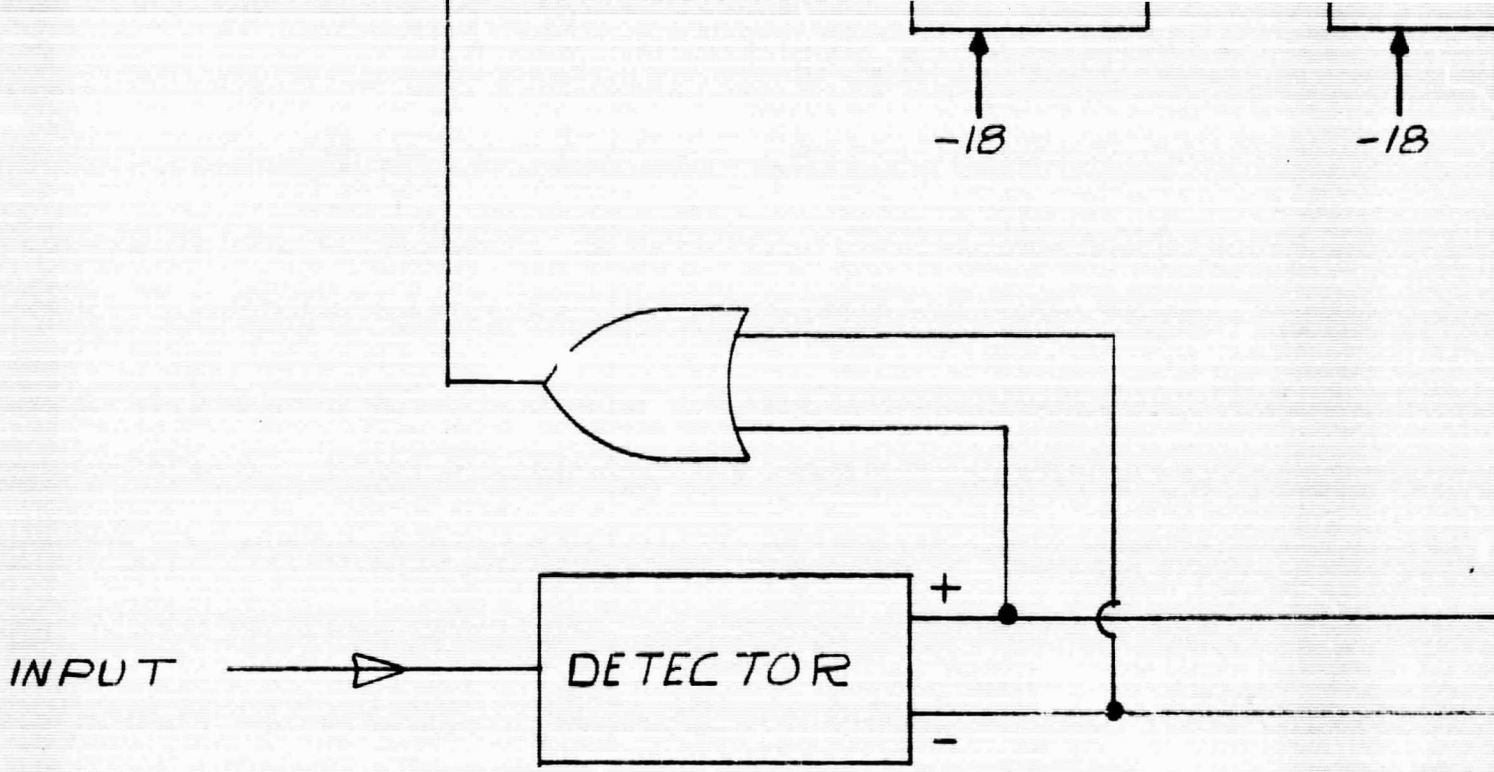
FULL	HIGH ALTITUDE ENGINEERING LABORATORY UNIVERSITY OF MICHIGAN DEPARTMENT OF AERO. AND ASTRO. ENGINEERING ANN ARBOR MICHIGAN
01114	
E3	
3-20-68	NAME MOUNT-MIRROR
AL. ALLOY	DRAWING NO. H3-52007
	III

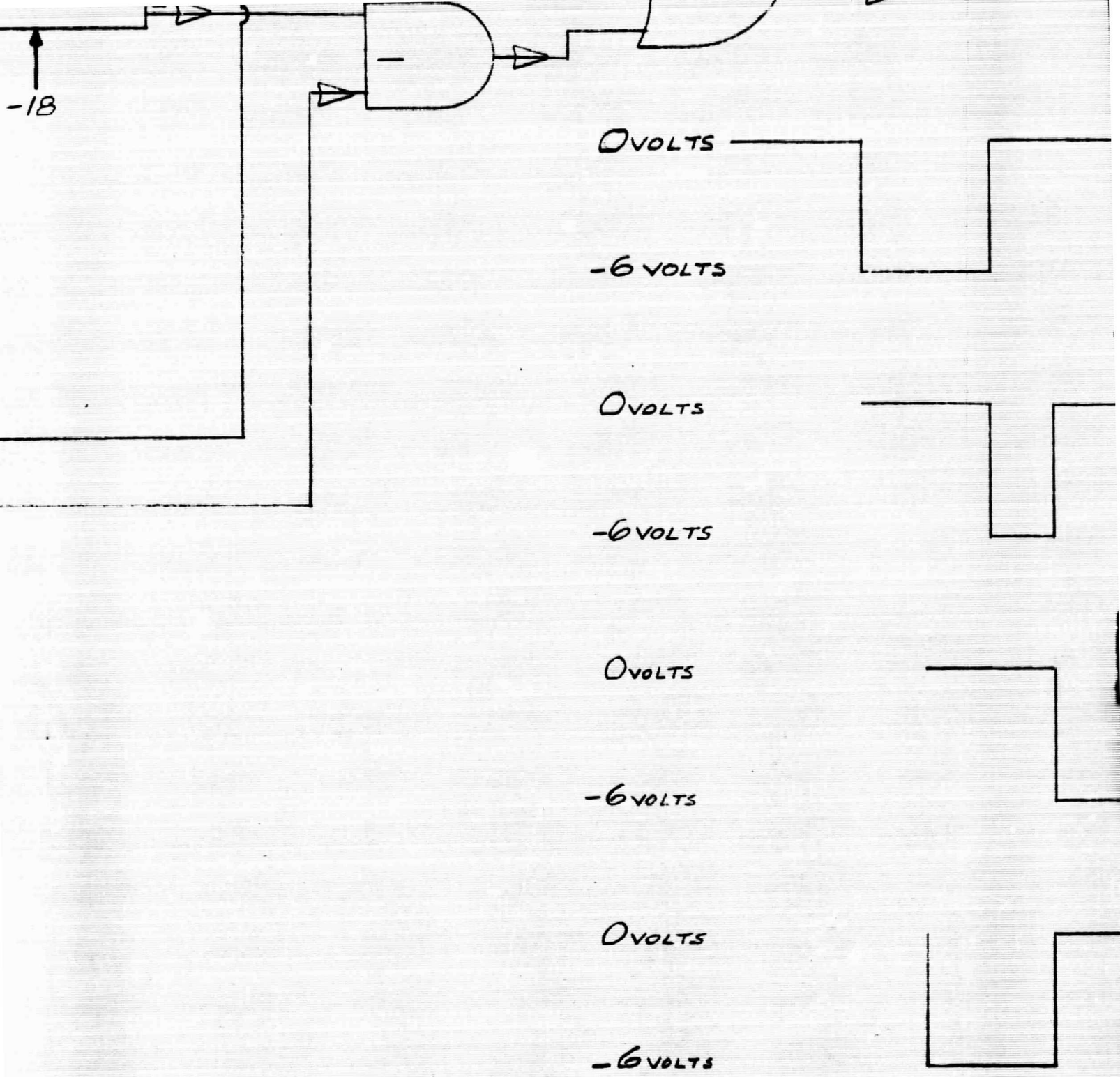
1


8.992
1.499
1.262
.635
5°
1.625


#1 DRILL THRU. (3) HOLES
EQUALLY SPACED ON 6.000 ± .003 B.C.
CHAMFER 45° .010 NOM.
.376 DIA. REF.
2.503
3.004


#7 DRILL THRU. (3) HOLES
DIA LIMITS .196 - .202
EQUALLY SPACED ON 4.125 ± .03
B.C. 120° C'SINK TO .23 DIA.
TAP WITH HELI-COIL #3FF-B-112.
B.C.
5°

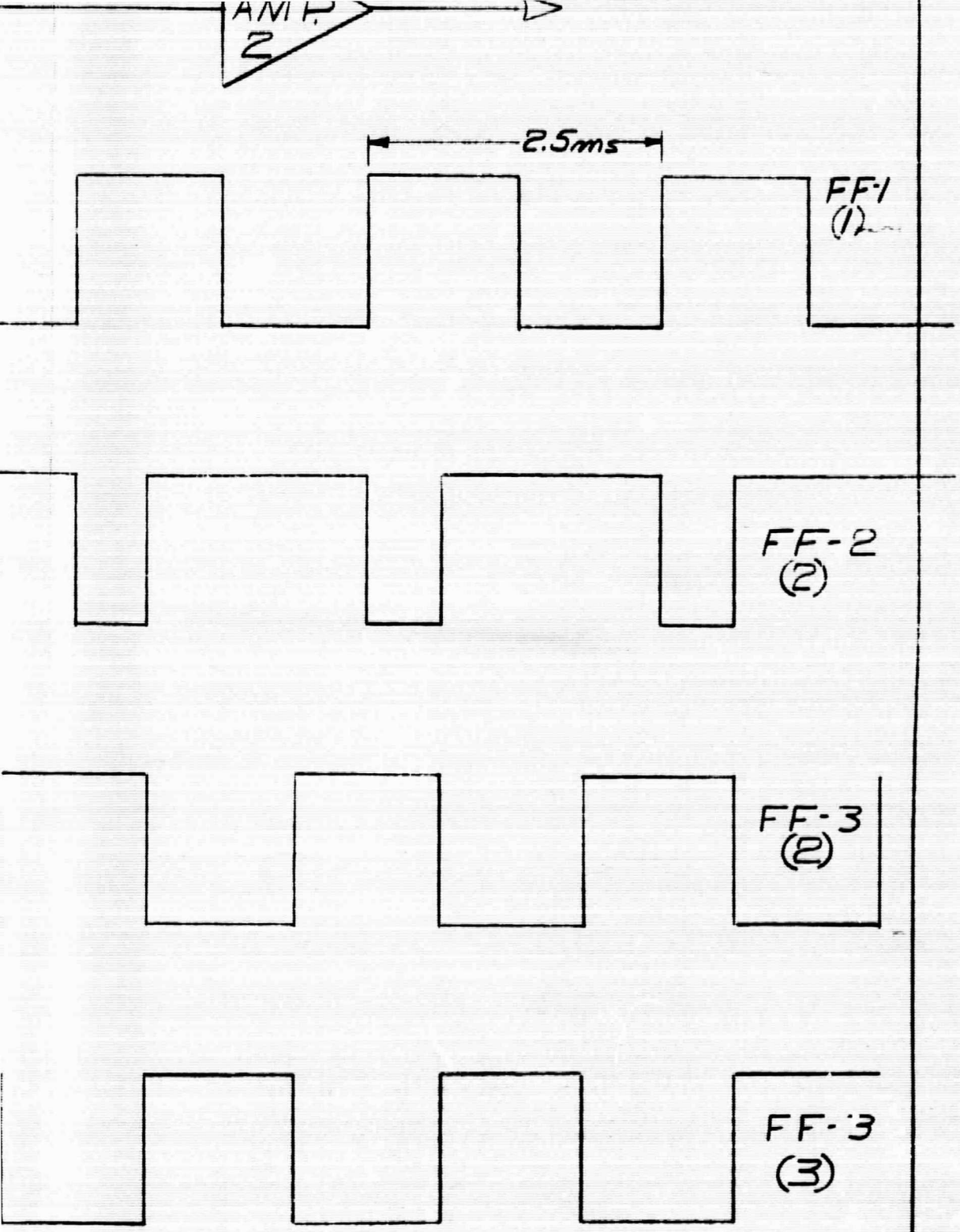

-18
-18
INPUT
DETECTOR
+
-



			SCALE	NONE
			PROJ. NO.	06647
			DRAWN BY	J.C. POUSA
			DATE	2-1-66
			FOR ASSEMBLY	
			DESIGN BY	D. HADDO
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

IV

1

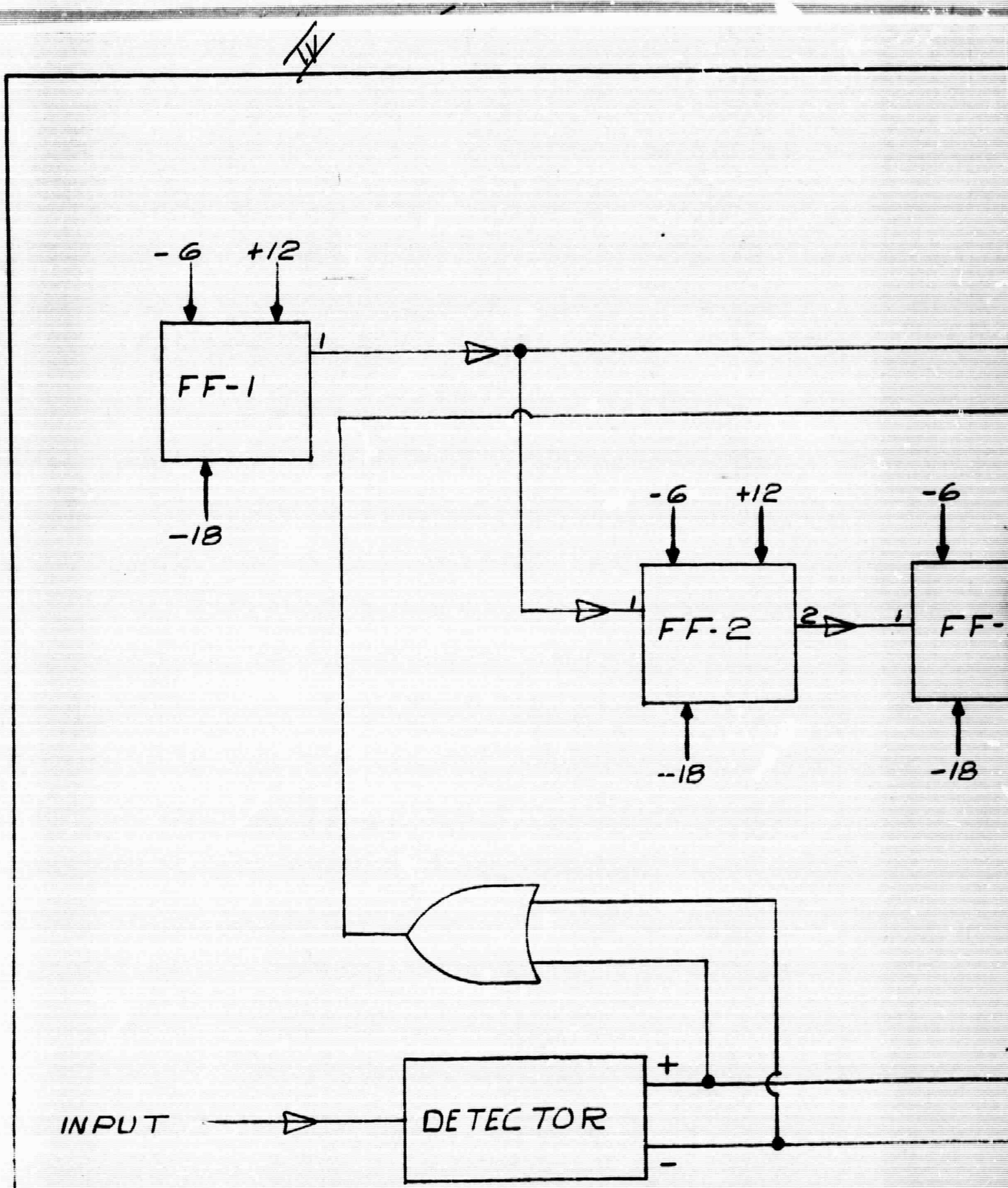


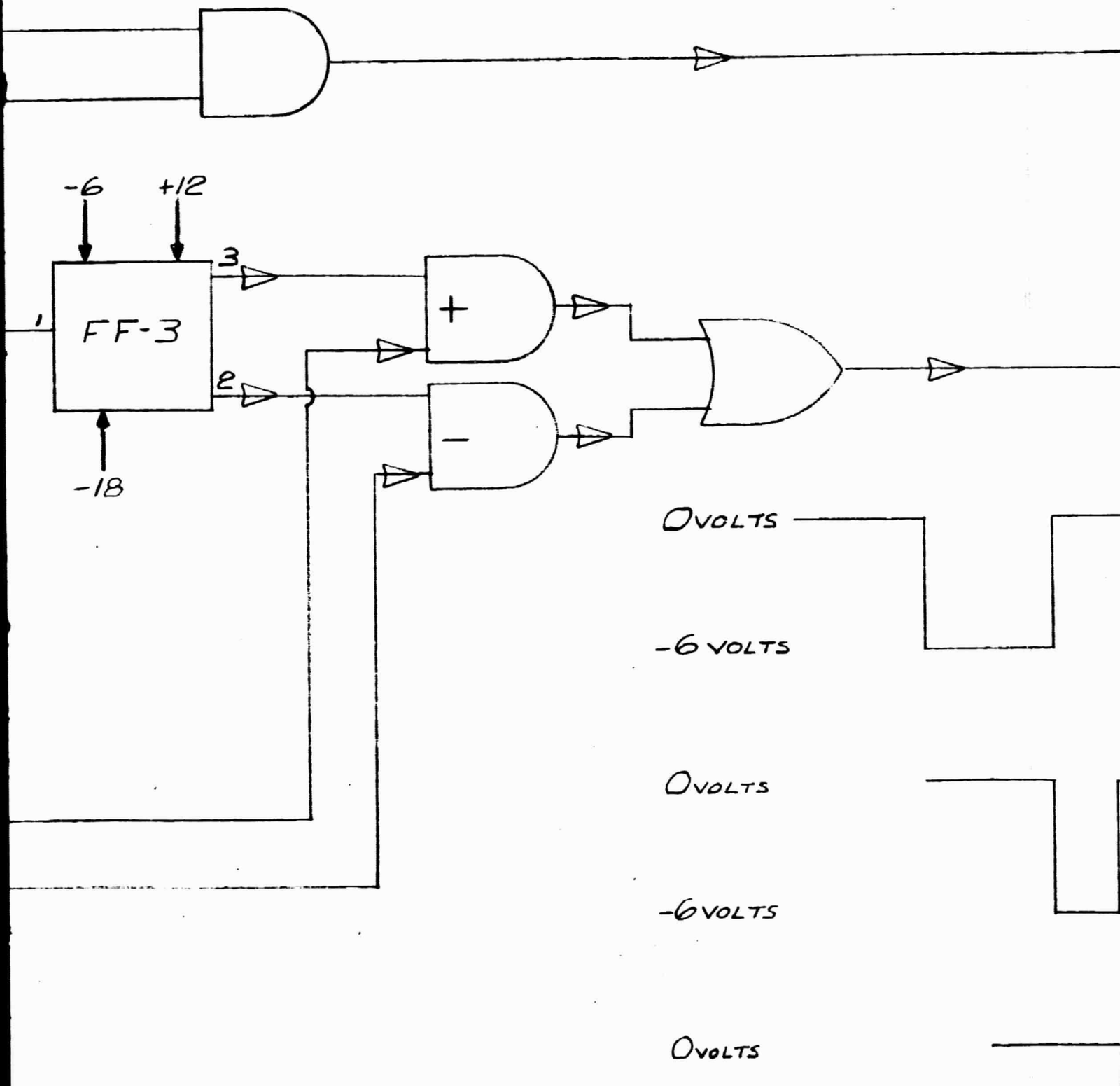
	NONE
	06647
	J.C. POUSAK
	2-1-66
	D. HADDOCK

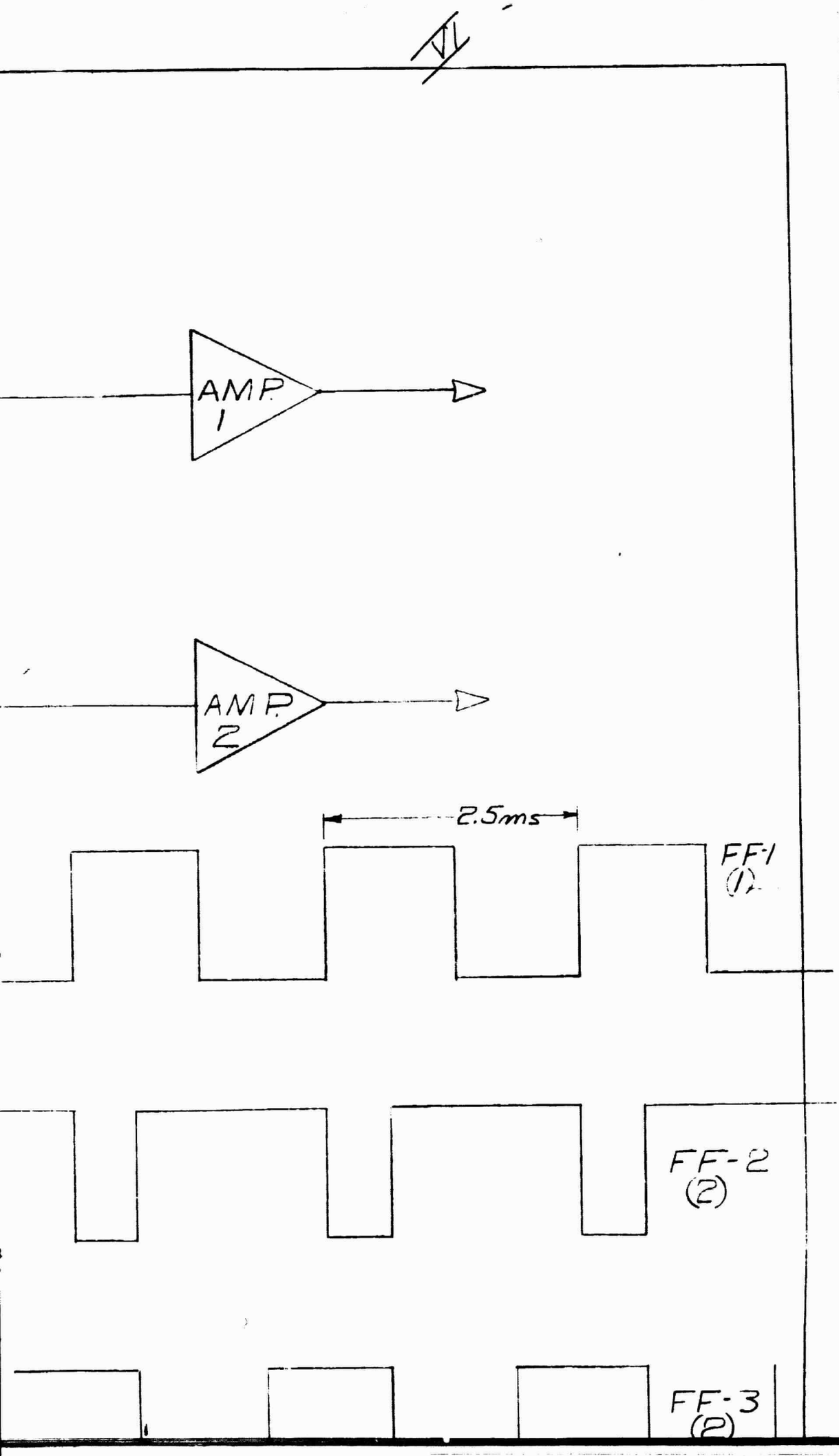
HIGH ALTITUDE ENGINEERING LABORATORY
UNIVERSITY OF MICHIGAN
DEPARTMENT OF AERO. AND ASTRO. ENGINEERING
ANN ARBOR MICHIGAN

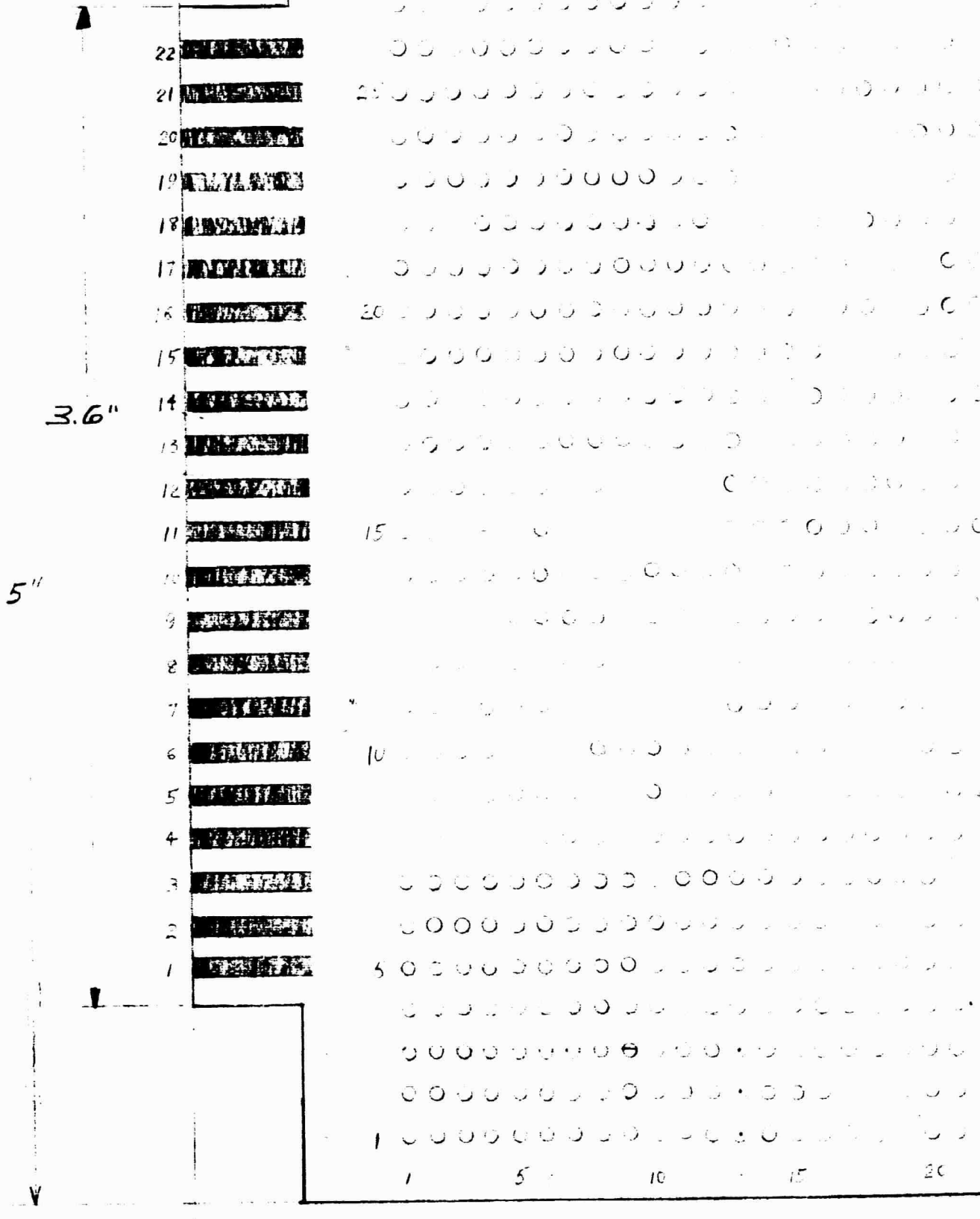
NAME LOGIC CIRCUIT & WAVE FORM FOR REACTION WHEEL

DRAWING NO. H3-52008

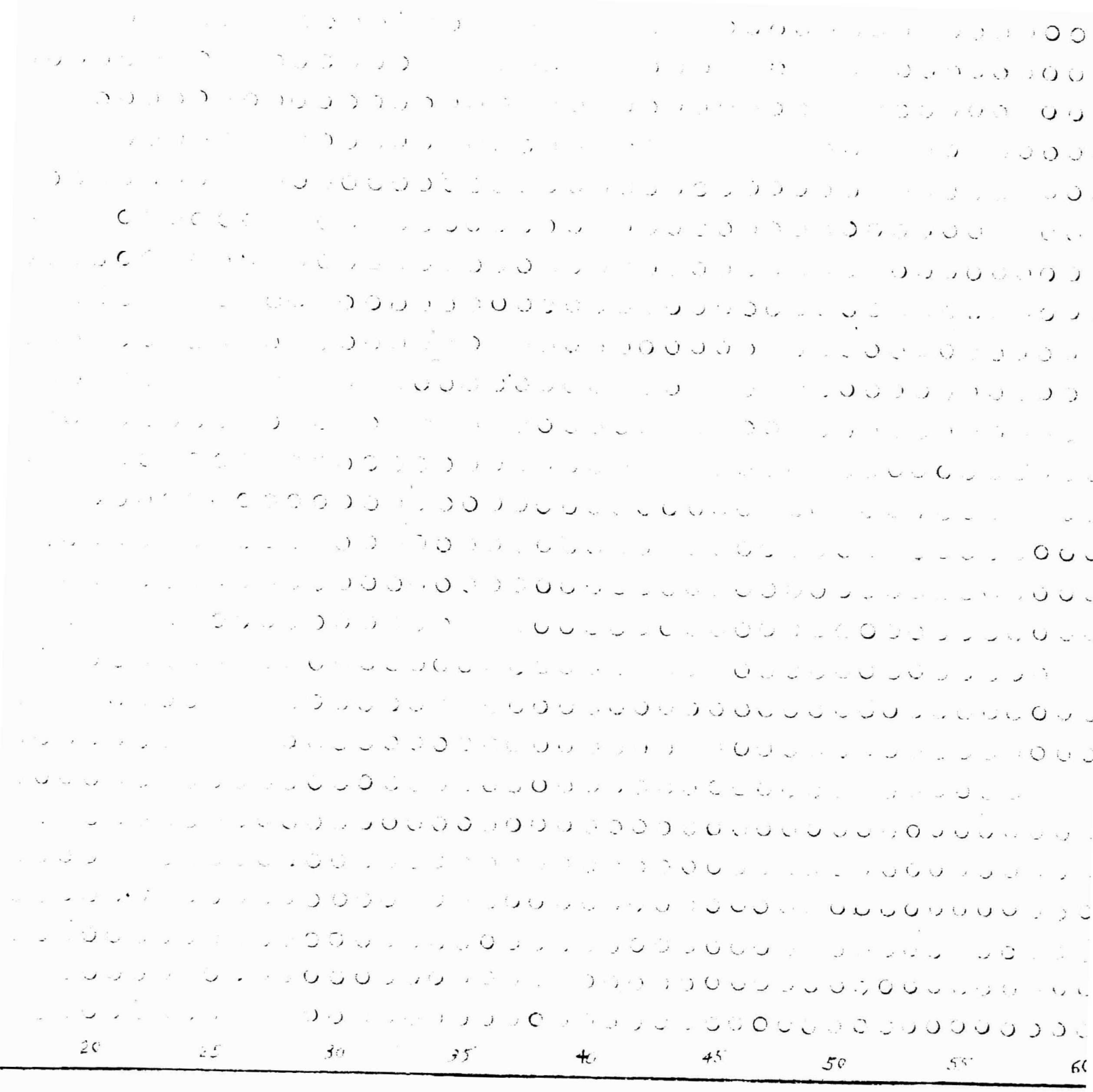

-6
+12
FF-1
1
-18
-6
+12
FF-2
1
2
1
FF-
-18
-18
+
DETECTOR
-
INPUT


-6
+12
3
1
FF-3
2
-18
+
−
0 VOLTS
-6 VOLTS
0 VOLTS
-6 VOLTS
0 VOLTS


AMP 1
AMP 2
2.5ms
FF-1 (1)
FF-2 (2)
FF-3 (2)


3.6"
5"
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
20
15
10
5
1
1
5
10
15
20

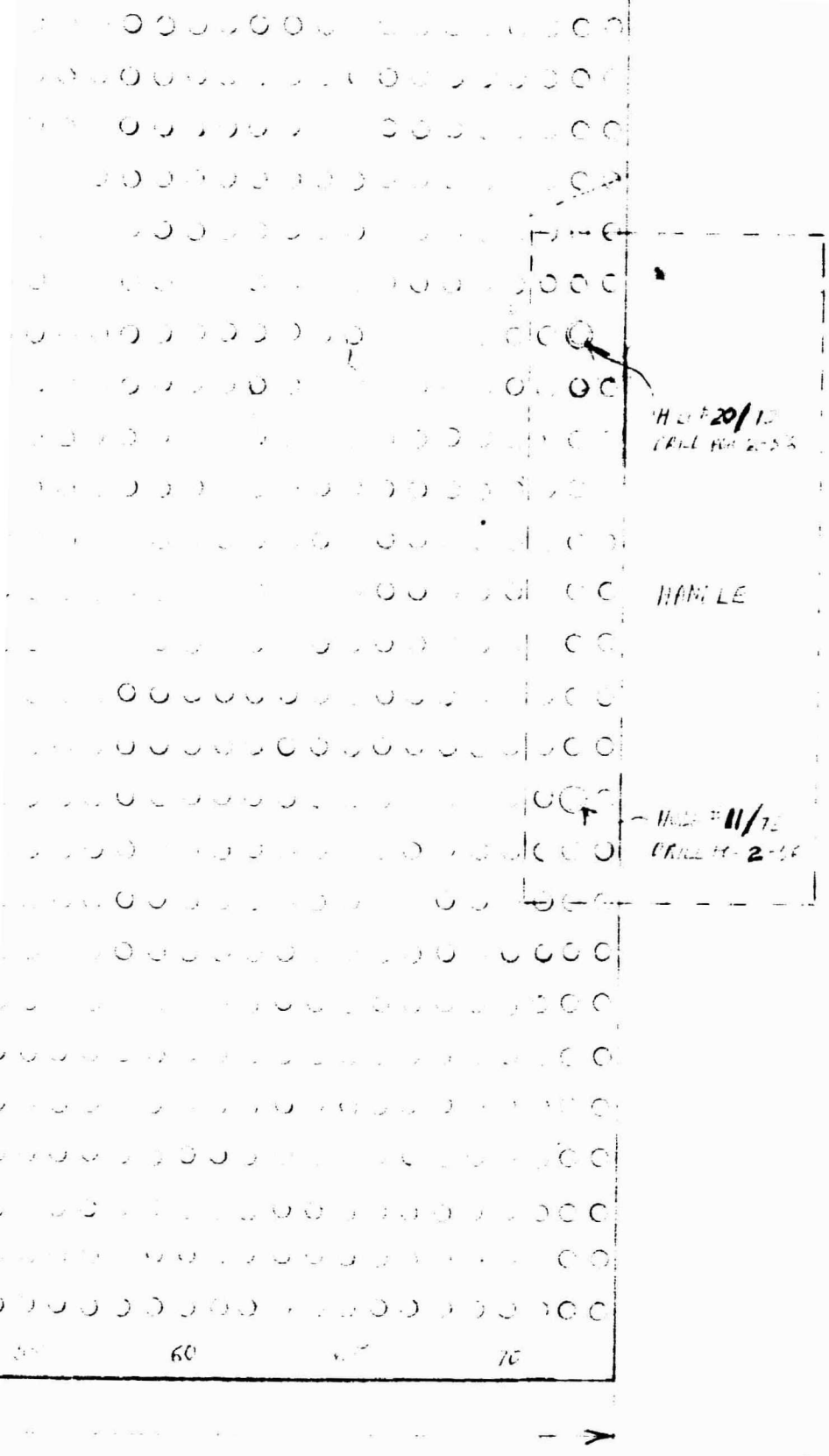
I



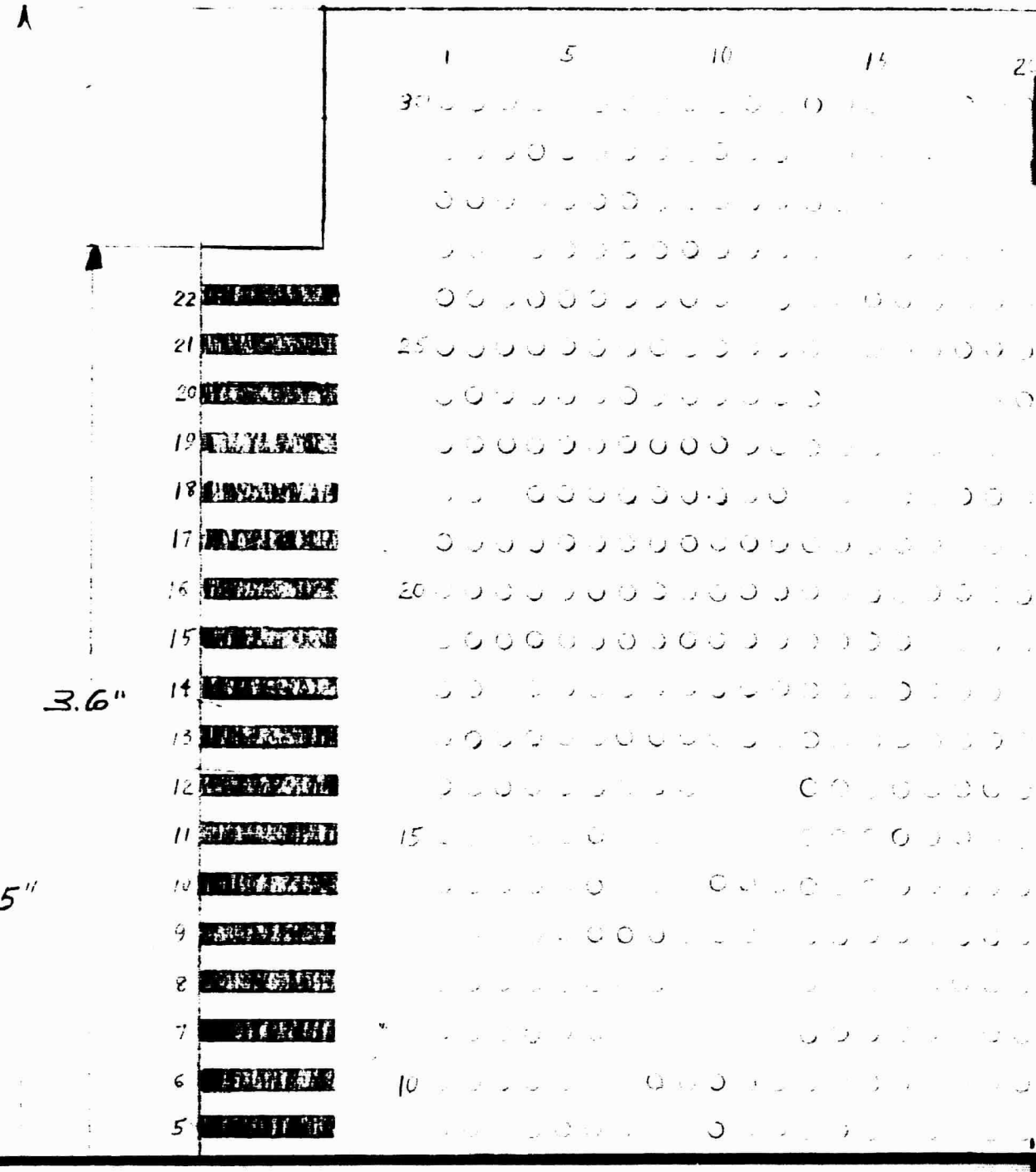
8"

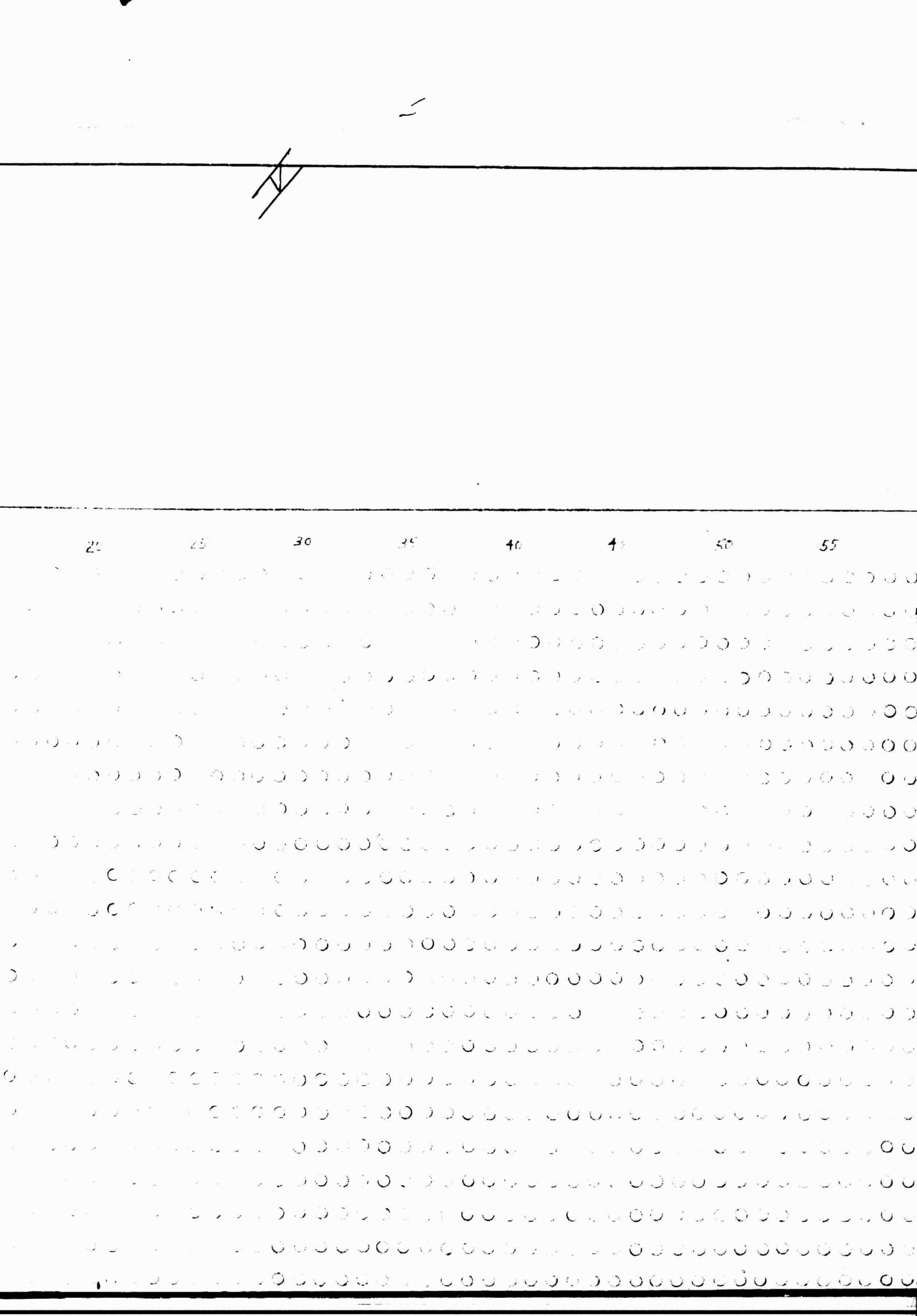
LET.	CHANGE	DATE
B	HANDLE POSITION CHANGED	3-15-68
A	REVISED	2-23-68

SCALE	2 TIM
PROJ. NO.	0664
DRAWN BY	J.C. P
DATE	8-22-
FOR ASSEMBLY	
MATERIAL	
WEIGHT CAL. ACT.	

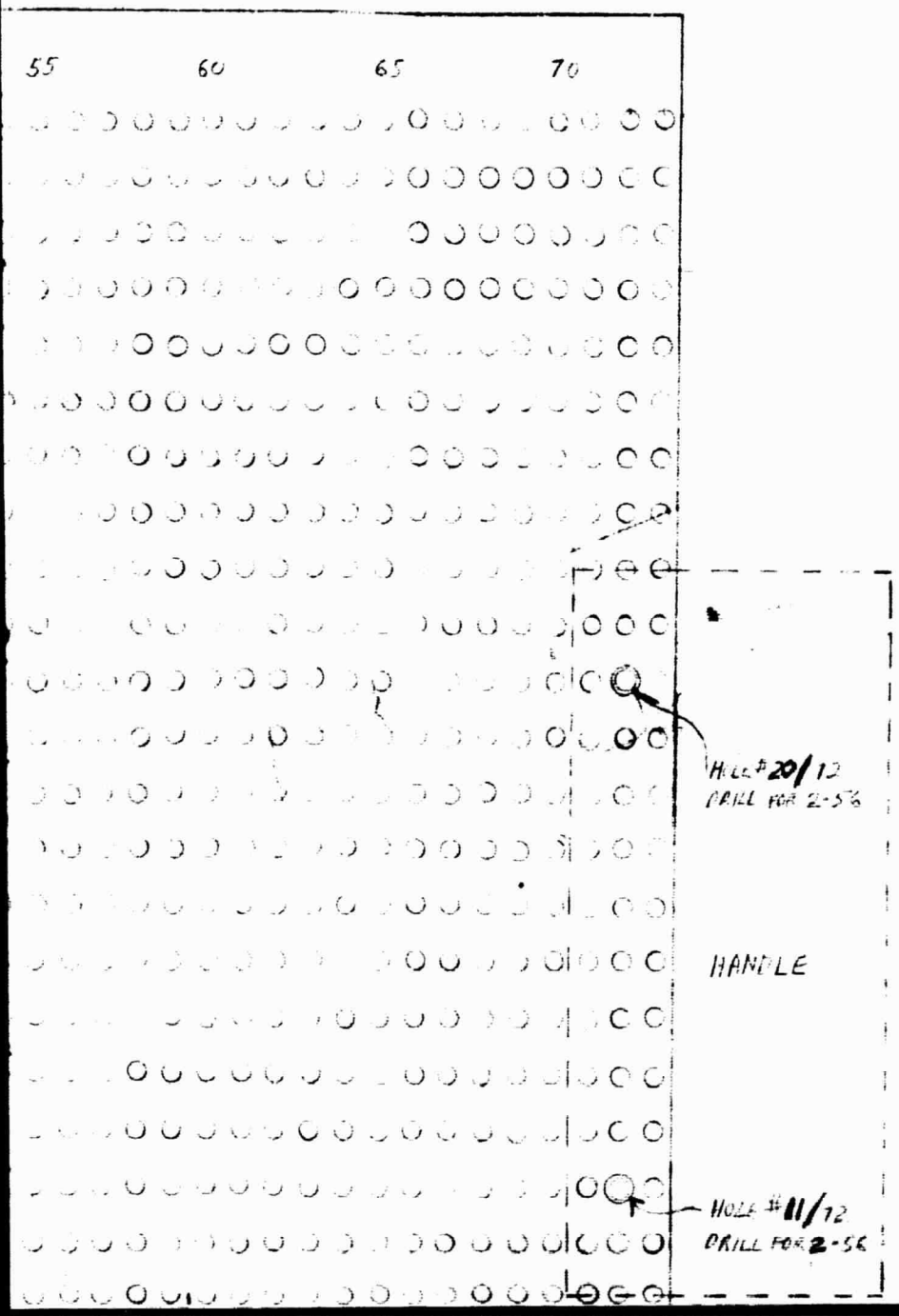


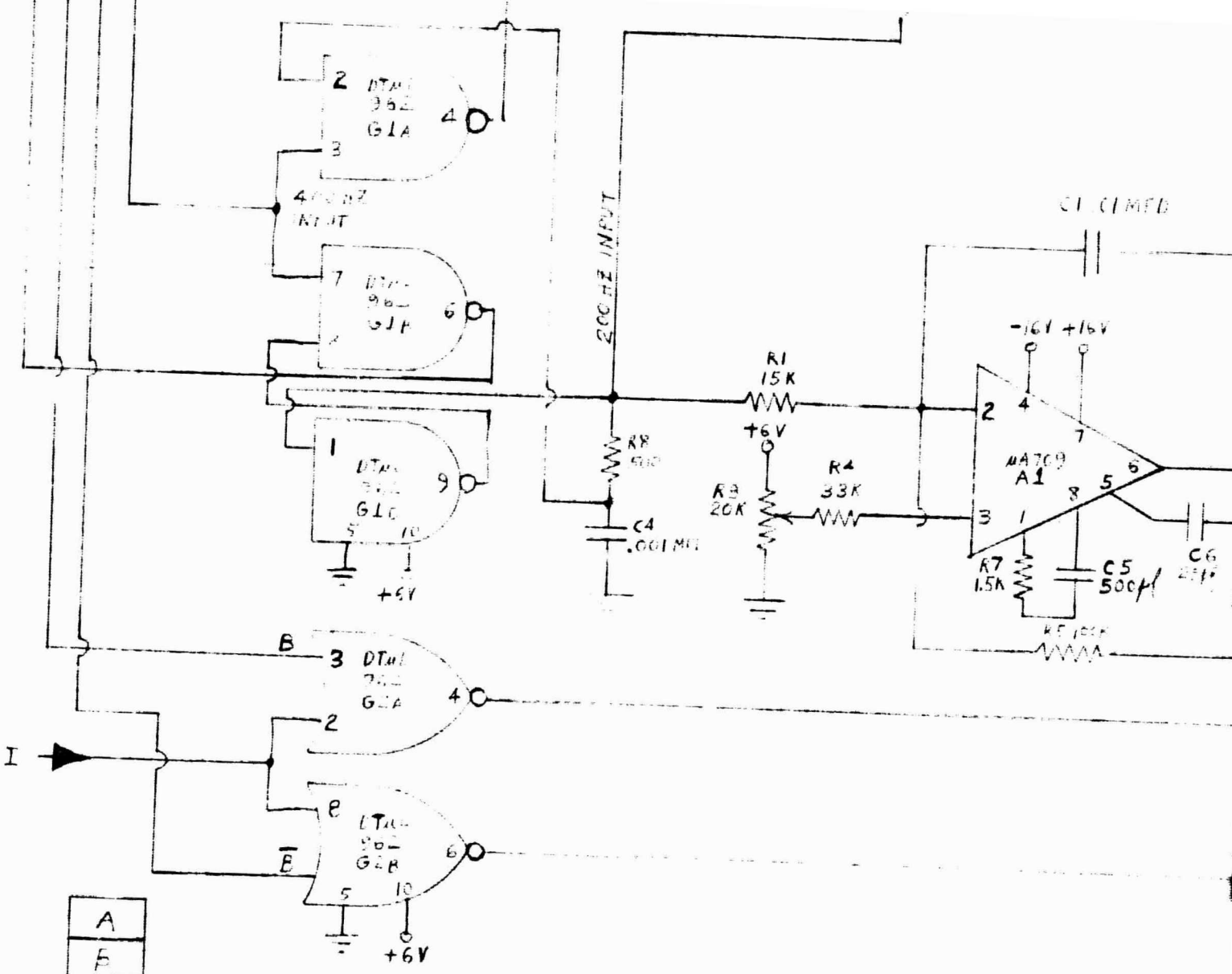
2 TIMES	HIGH ALTITUDE ENGINEERING LABORATORY UNIVERSITY OF MICHIGAN DEPARTMENT OF AERO. AND ASTRO. ENGINEERING ANN ARBOR MICHIGAN
06647	
J.C. POUSAK	
8-22-66	NAME VERO BOARD LAYOUT — COMPONENT SIDE
	DRAWING NO. H3-52009


1
5
10
15
30
25
20
15
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
3.6"
5"

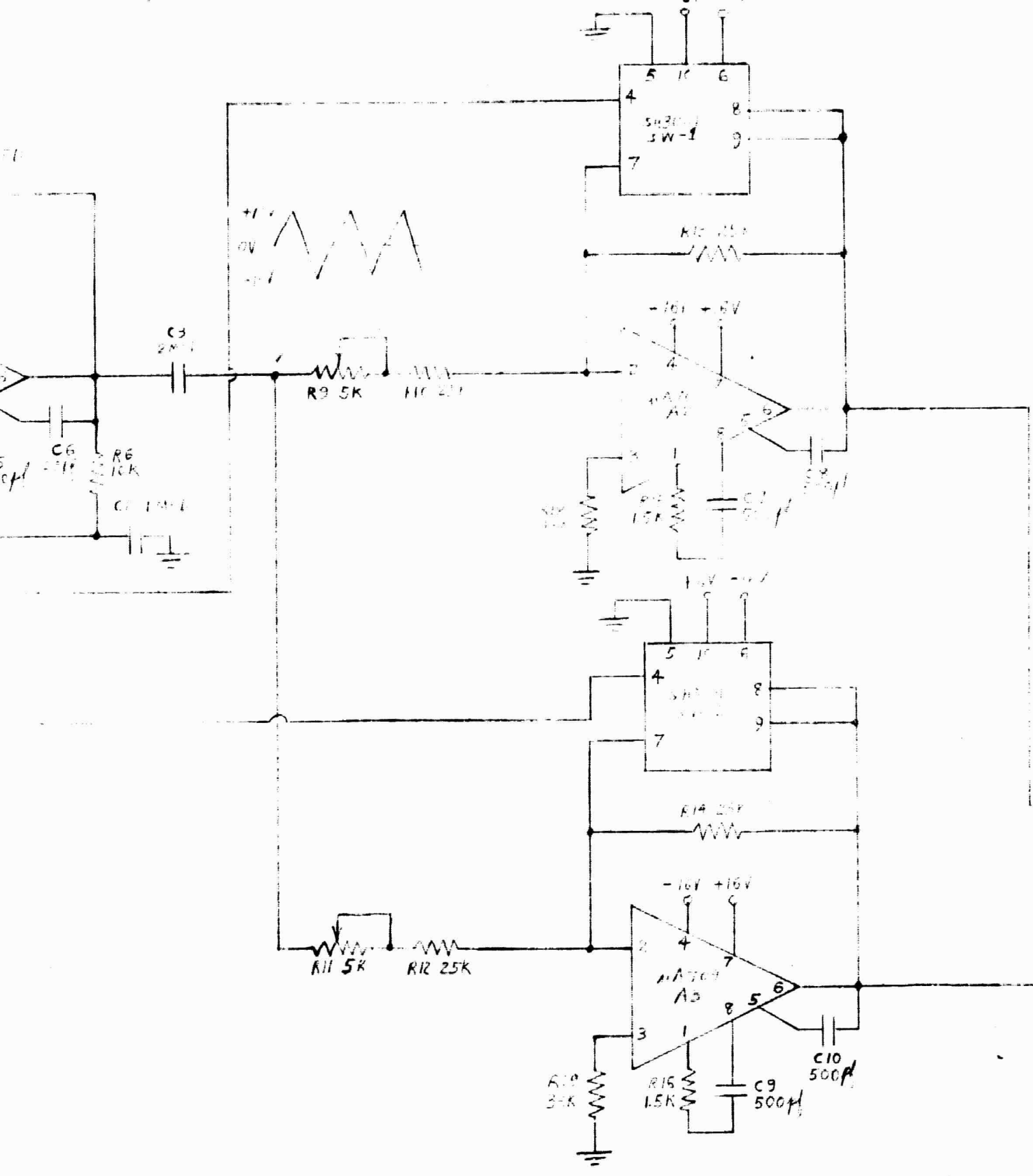


VI

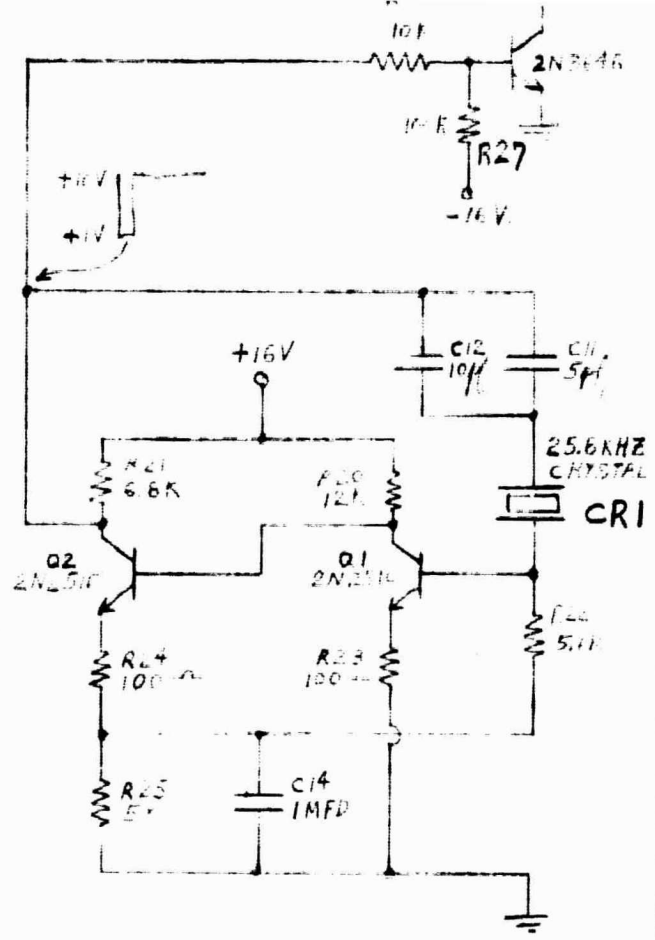

55
60
65
70
HOLE #20/12
DRILL FOR 2-56
HANDLE
HOLE #11/12
DRILL FOR 2-56



A	
B	
C	
D	
E	
F	
H	
J	
K	
L	400 HZ OUTPUT
M	$\overline{C}$
N	$\overline{B}$
P	I - INHIBIT
R	B 100 HZ OUTPUT
S	C 200 HZ OUTPUT
T	+6V, 87MA.
U	GROUND
V	
W	HORIZ. OUTPUT
X	VERT OUTPUT
Y	-16V. (-15V, 14MA)
Z	+16V. (+15V, 14MA.)



			SCALE	NONE
			PROJ. NO.	6114
			DRAWN BY	T. MARTINSON
			DATE	2-19-68
			FOR ASSEMBLY	
A	B & C WAVESHAPES ADDED	2-20	MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

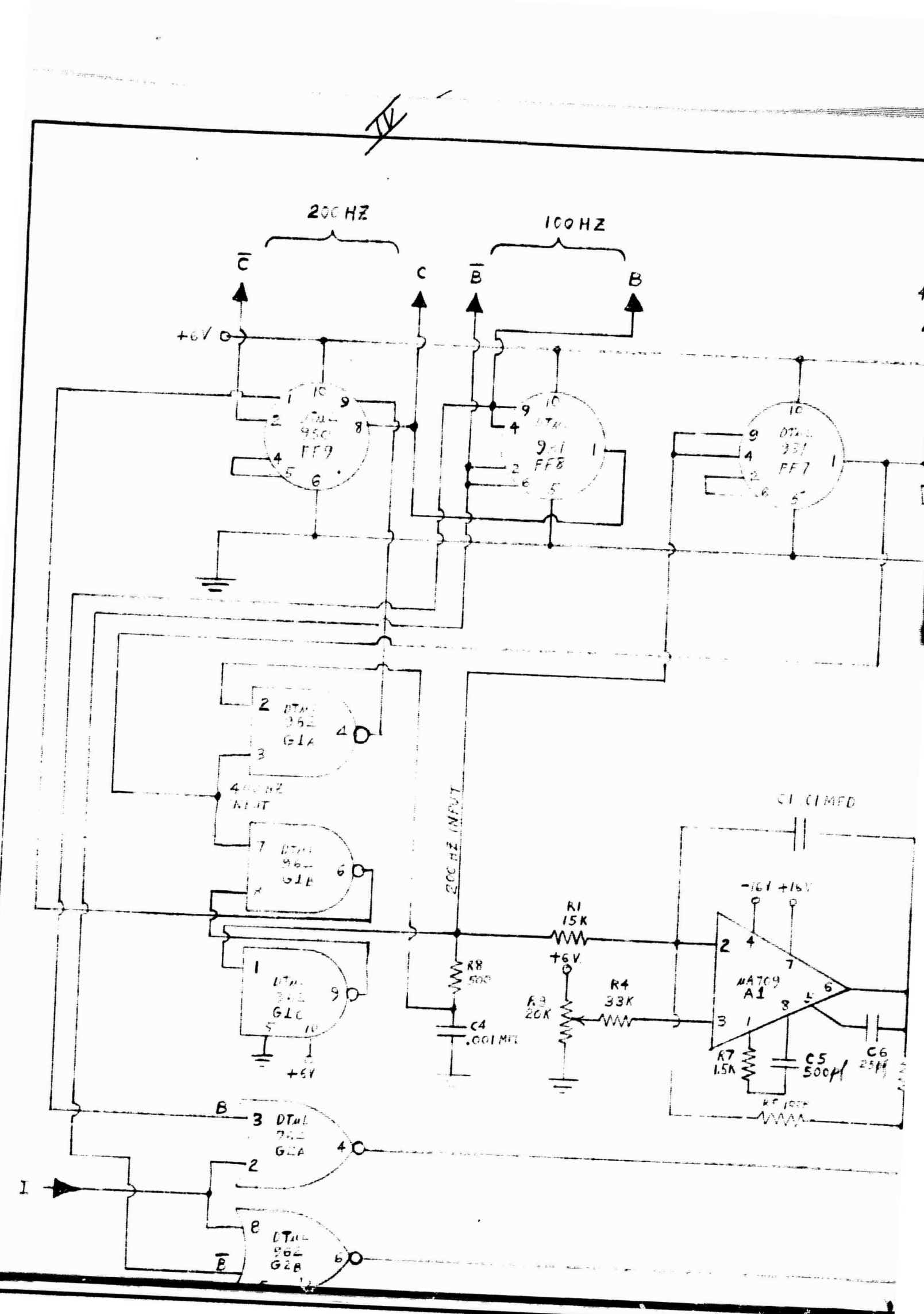


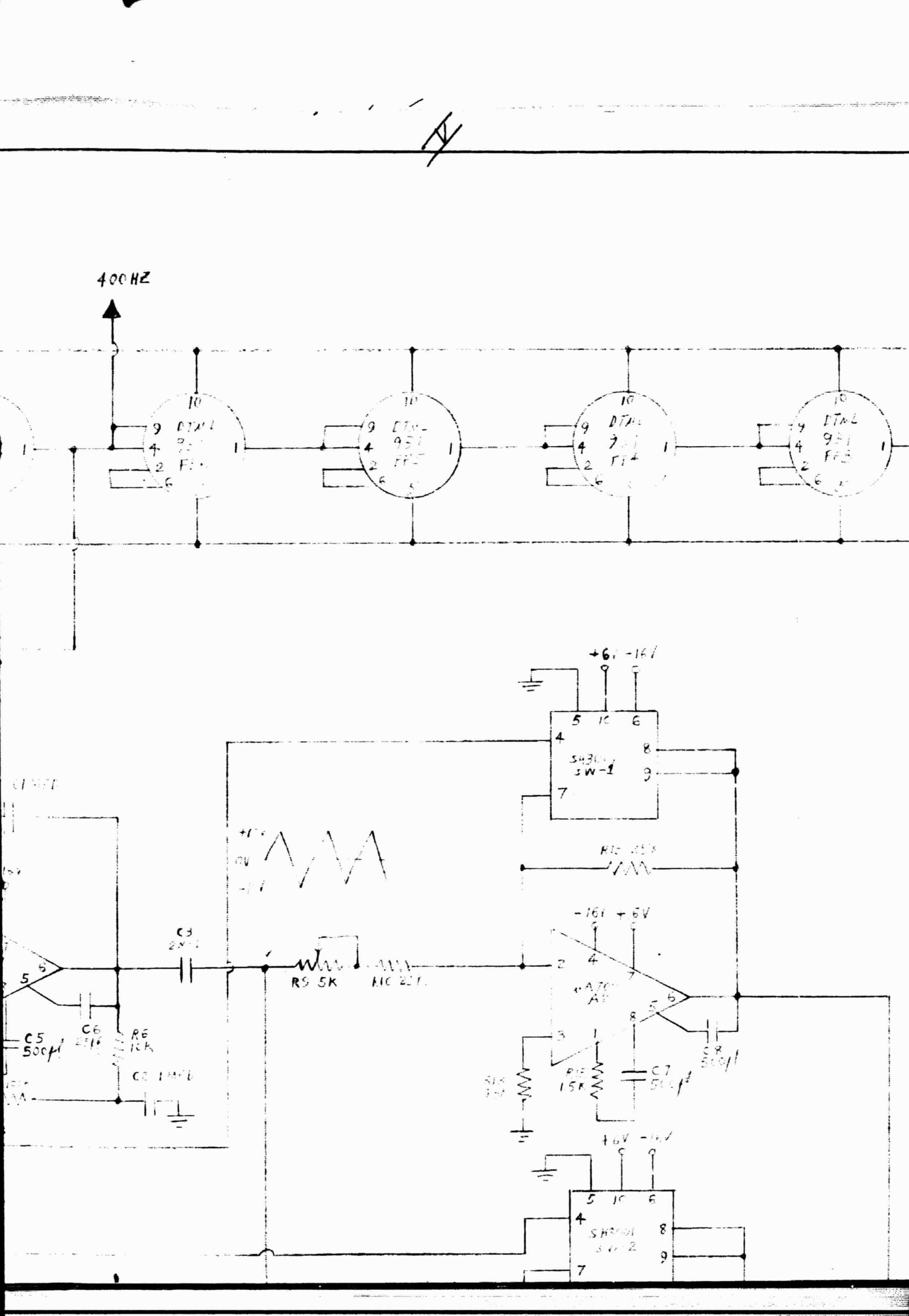
	NONE
D.	[illegible]
	T.I.A. TH-5001
	2-14-68
LY	
AL	
AL. ACT.	

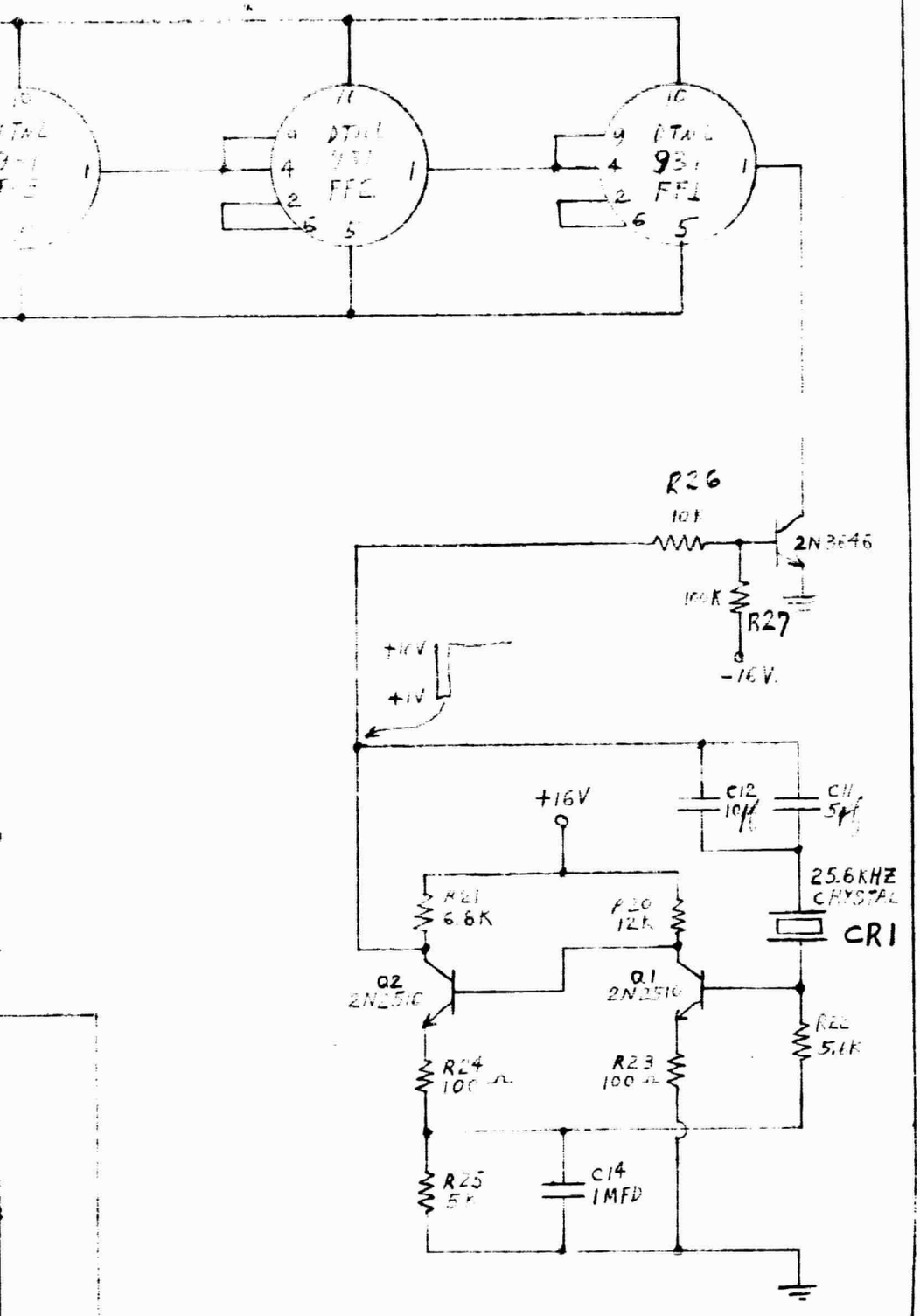
HIGH ALTITUDE ENGINEERING LABORATORY
UNIVERSITY OF MICHIGAN
DEPARTMENT OF AERO. AND ASTRO. ENGINEERING
ANN ARBOR MICHIGAN

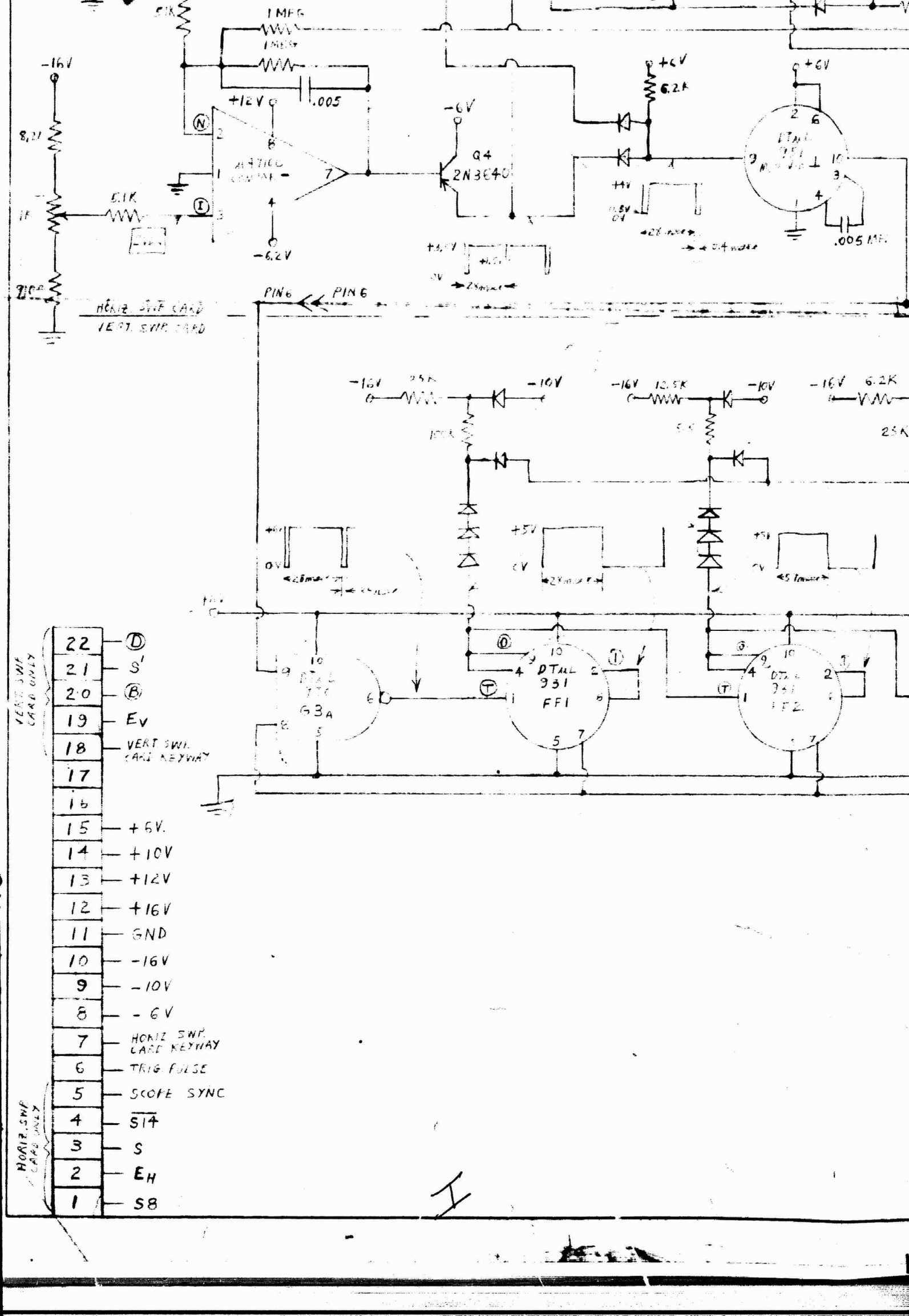
NAME ATWILL SCAN GENERATOR

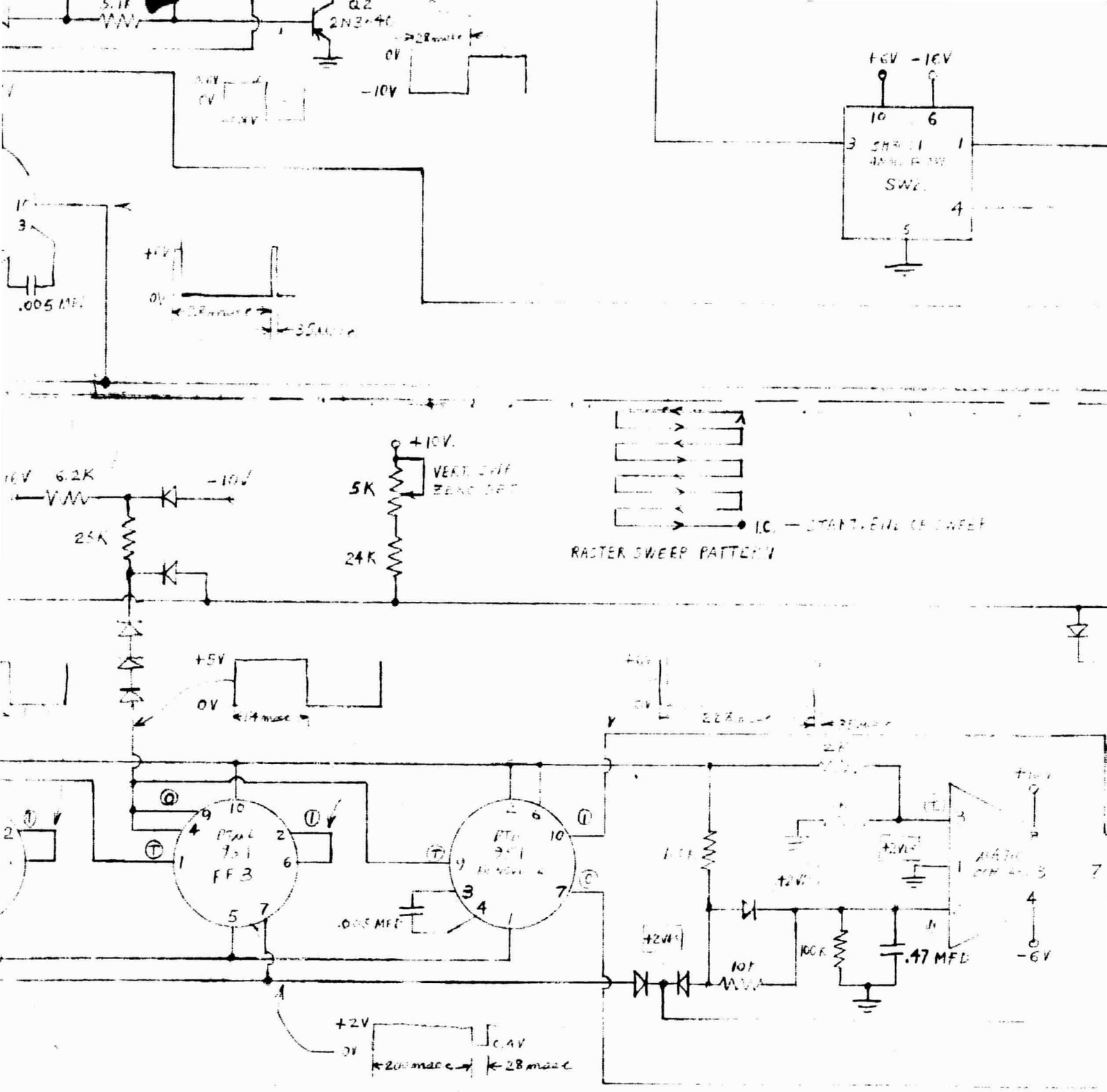
DRAWING NO. H3-52010


200 HZ
100 HZ
C̄
C
B̄
B
+6V
DTμL 930 FF9
DTμL 931 FF8
DTμL 931 FF7
DTμL 962 G1A
DTμL 962 G1B
DTμL 962 G1C
DTμL 962 G2A
DTμL 962 G2B
200 HZ INPUT
R1 15K
R8 500
R4 33K
R3 20K
C4 .001 MFD
C1 .01 MFD
-16V +16V
μA709 A1
R7 1.5K
C5 500pf
C6 25pf
I


400 HZ
+6V -16V
C3
RS 5K
C5
500pf
C6
R6
15K
C7
R8
15K
+6V -16V

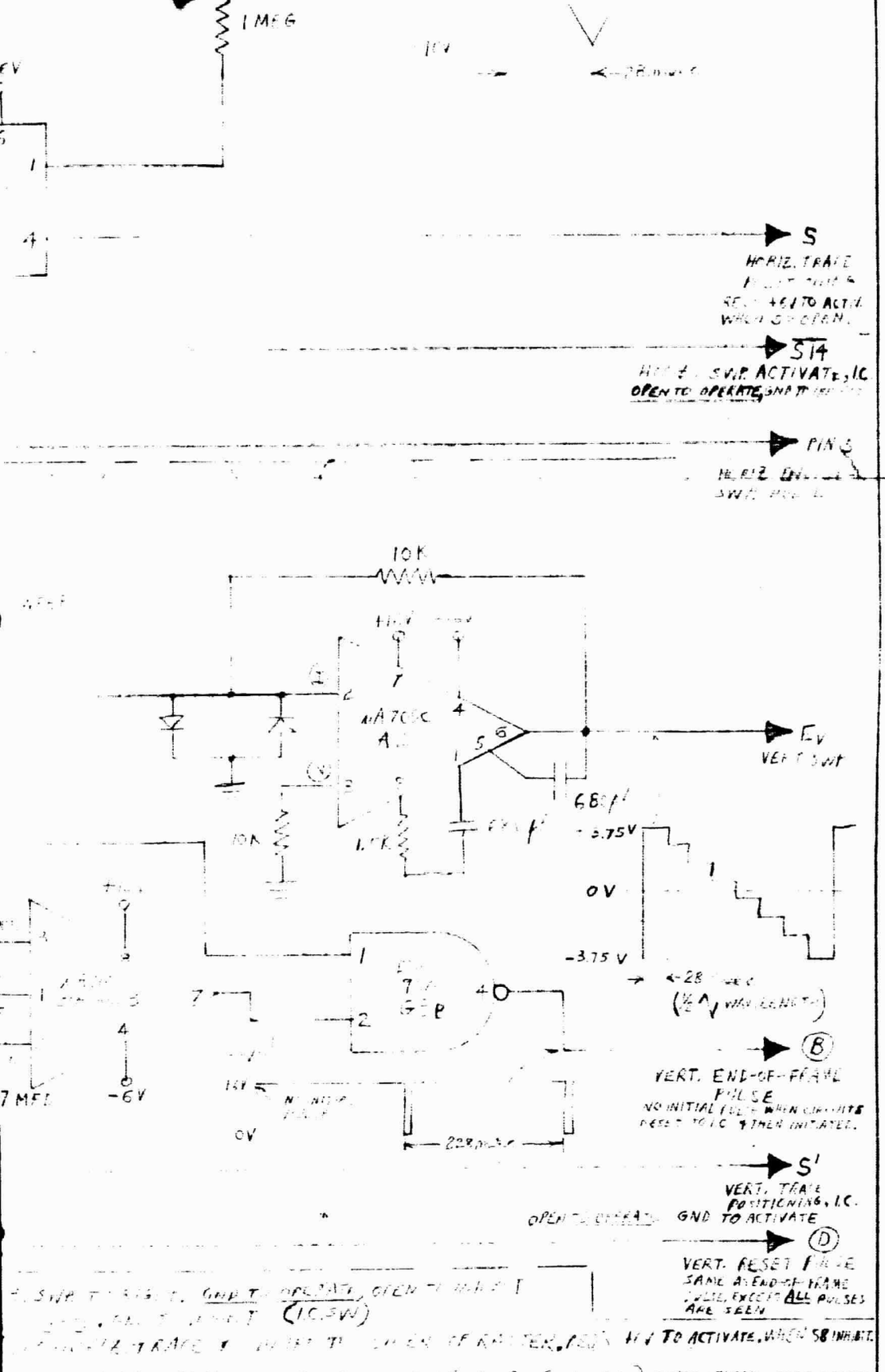

R26
10K
2N3646
100K
R27
-16V.
+16V
+1V
+16V
C12
10μf
C11
5pf
25.6KHZ
CRYSTAL
CR1
R21
6.6K
R20
12K
Q2
2N2510
Q1
2N2510
R22
5.1K
R24
100Ω
R23
100Ω
R25
5K
C14
1MFD


-16V
8.2K
1K
5.1K
2.0K
5.1K
1 MEG
1 MEG
.005
+12V
-6.2V
-6V
Q4
2N3640
+6V
6.2K
.005 MF.
PIN 6
PIN 6
HORIZ SWP CARD
VERT. SWP. CARD
-16V 2.5K
-16V 12.5K
-16V 6.2K
25K
+5V
0V
DTμL 930 G3A
DTμL 931 FF1
DTμL 931 FF2
22 Ⓓ
21 S'
20 Ⓑ
19 EV
18 VERT SWP. CARD KEYWAY
17
16
15 +6V.
14 +10V
13 +12V
12 +16V
11 GND
10 -16V
9 -10V
8 -6V
7 HORIZ SWP. CARD KEYWAY
6 TRIG. PULSE
5 SCOPE SYNC
4 S14
3 S
2 EH
1 S8
VERT. SWP. CARD ONLY
HORIZ. SWP. CARD ONLY



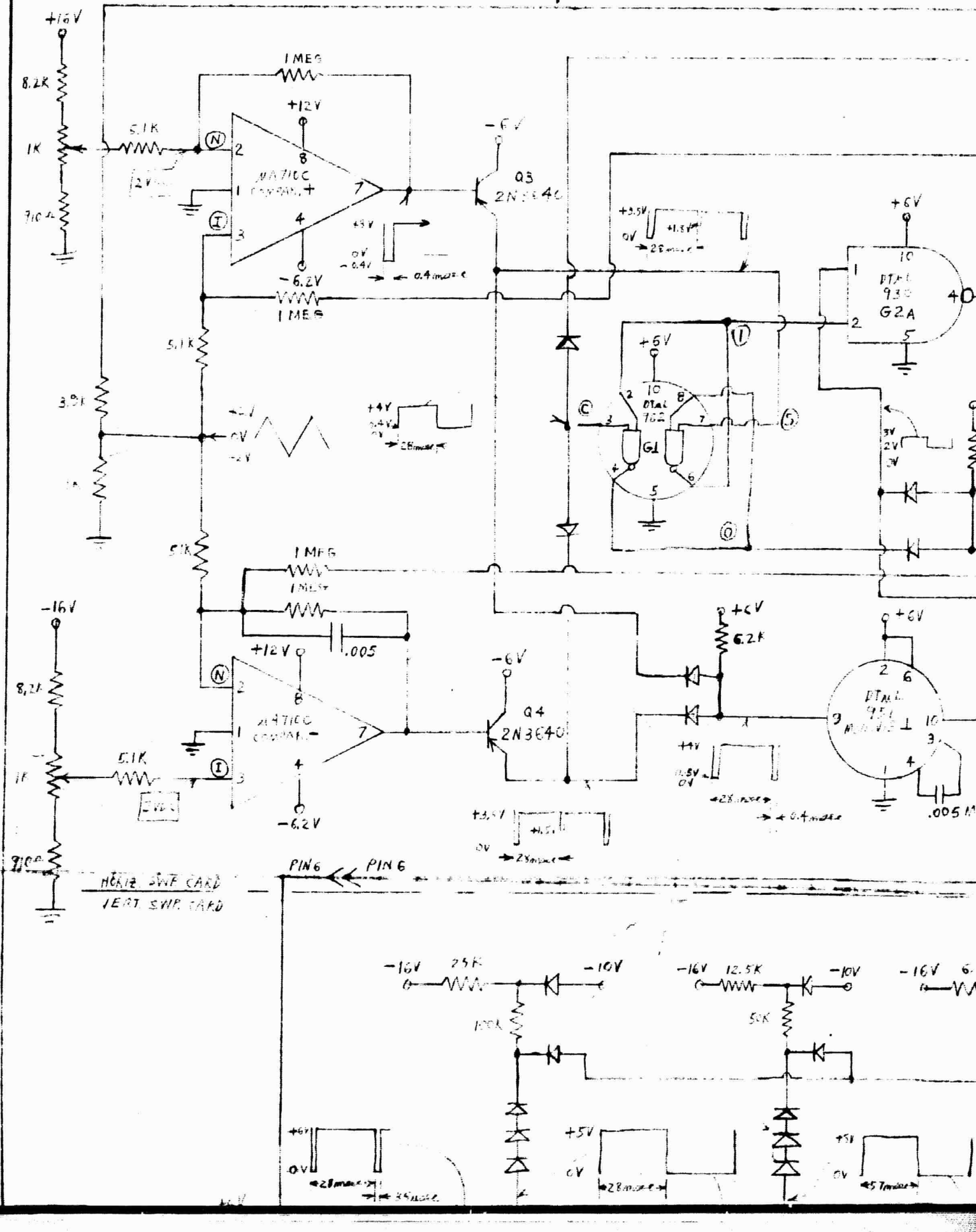
NOTES: 1. S8 IS I.C. (INTENSITY CONTROL) SW TO RETURN HOME SWR TO RIGHT. G
2. $\overline{S14}$ IS HOME SWR ACTIVATED, N
3. S WHEN CLOSED & WHEN $\overline{S14}$ IS [illegible], ALLOWS HORIZ TRACE
4. S' WHEN GROUNDED & WHEN $\overline{S12}$ IS [illegible] RESETS VERT. TRA
5. ALL UNMARKED DIODES ARE FAIRCHILD IN486B

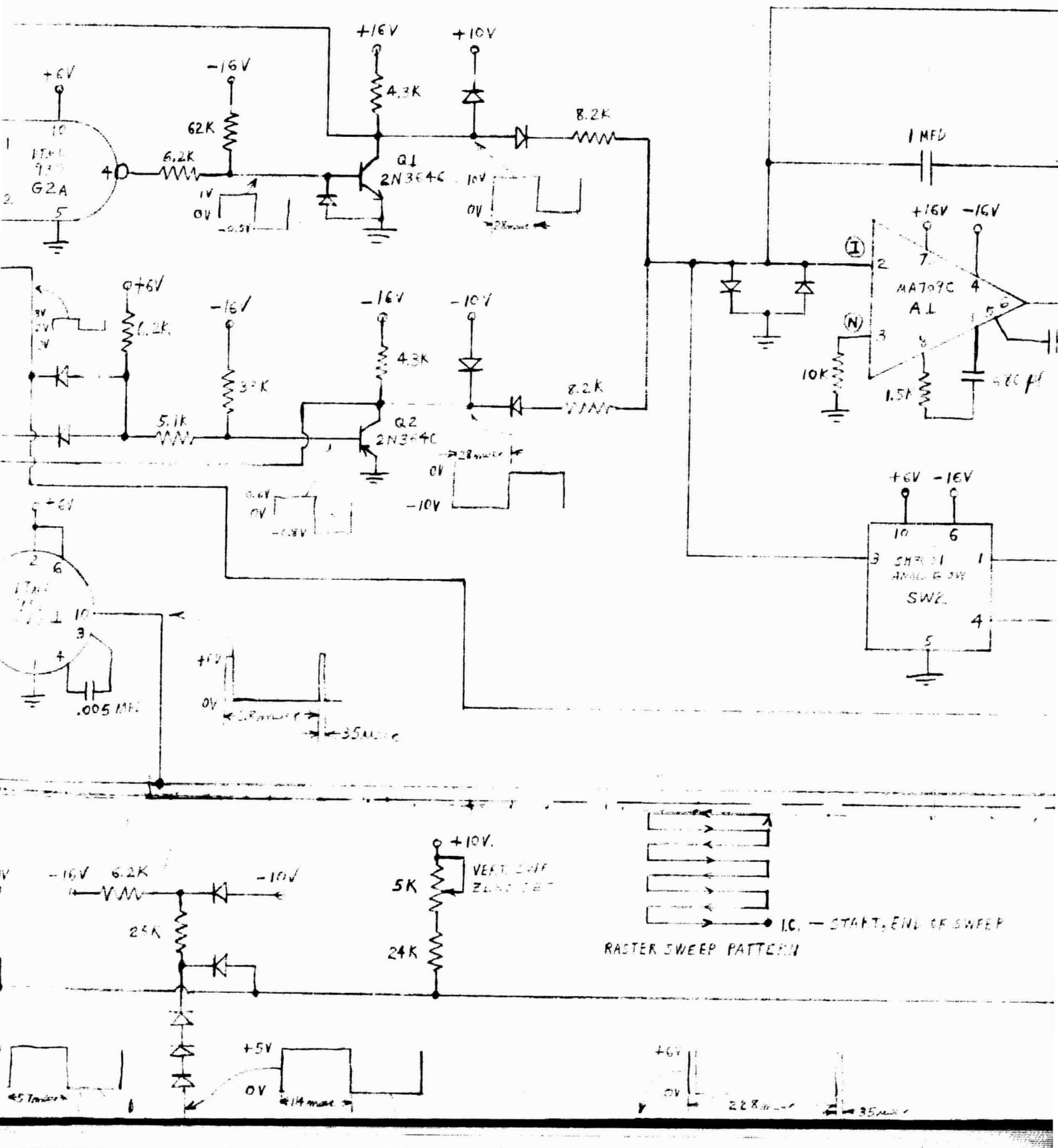
			SCALE	NONE
			PROJ. NO.	01114
			DRAWN BY	T. PATTINSON
C	VOLTAGE DIVIDERS REMOVED. 5K POT. & 24K RESIST TO A2. CHGD VERT. SWR. VOLTAGE LEVELS. ADDED CONNECTOR 1 IN DESIGNATIONS.	4-1-68	DATE	2-5-68
B	ADDED .005MFD TO -COMP. 2.2MFD TO .47MFD AT C3, PIN 2	3-26-68	FOR ASSEMBLY	
A	MAJOR REVISIONS	2-4-68	MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

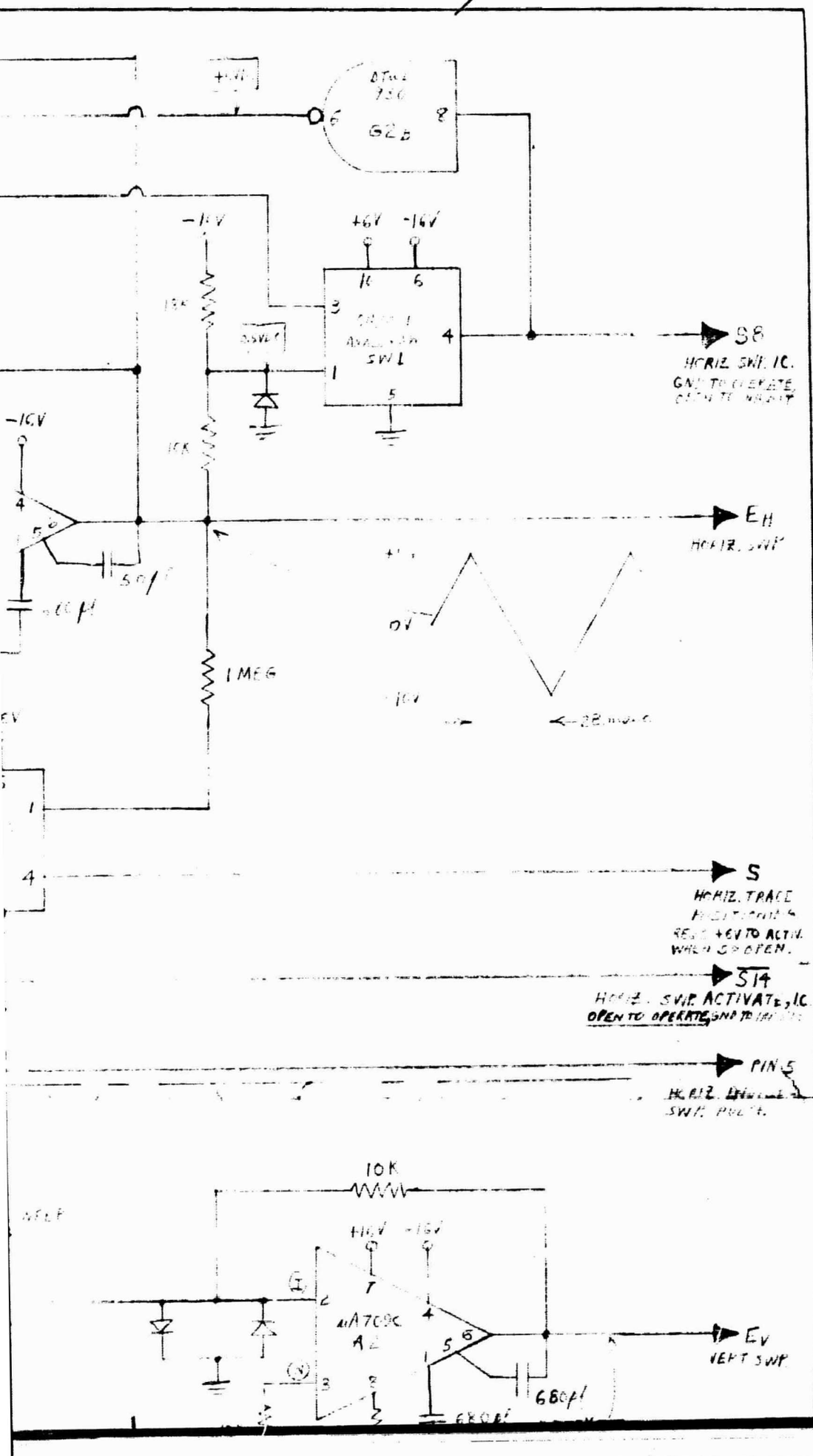


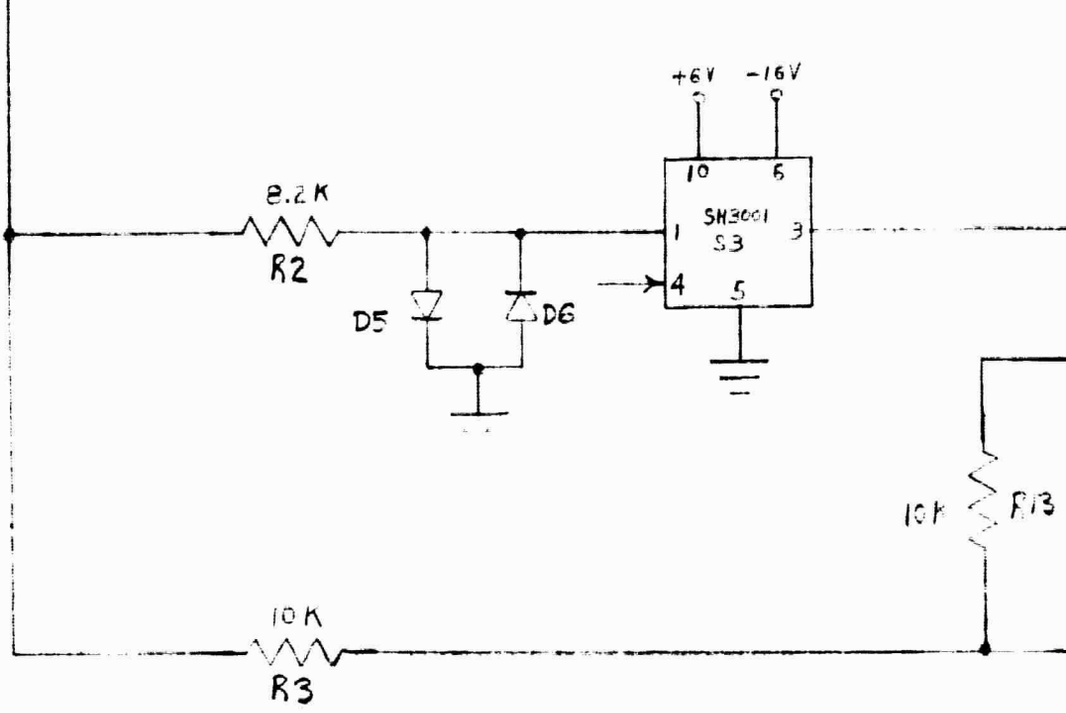
NAME	HIGH ALTITUDE ENGINEERING LABORATORY UNIVERSITY OF MICHIGAN DEPARTMENT OF AERO. AND ASTRO. ENGINEERING ANN ARBOR MICHIGAN
NONE	
01114	
T. PATTINSON	
2-5-68	
	NAME HORIZ. AND VERTICAL RASTER SCAN GENERATOR
	DRAWING NO. H3-52011

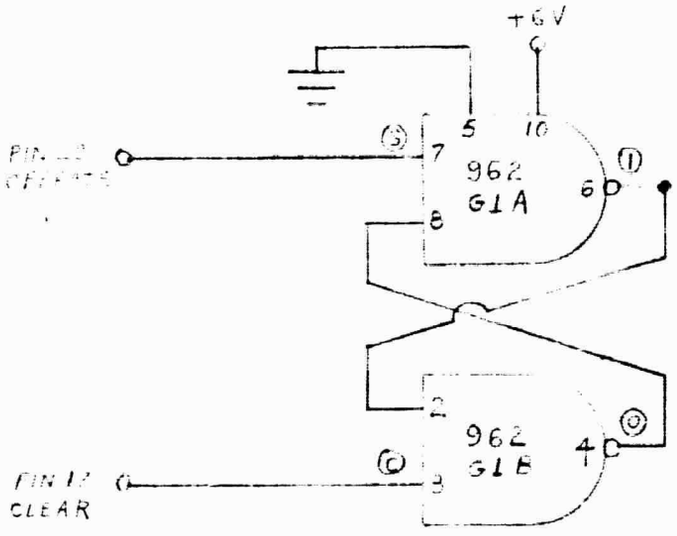
IV


+16V
8.2K
1K
710Ω
1MEG
5.1K
+12V
-6V
Q3
2N3640
-6.2V
3.9K
+6V
DTμL 930
G2A
DTμL 702
G1
.005
-16V
Q4
2N3640
6.2K
DTμL 951
PIN 6
PIN 6
HORIZ. SWP CARD
VERT. SWP CARD
25K
100K
12.5K
50K
-10V

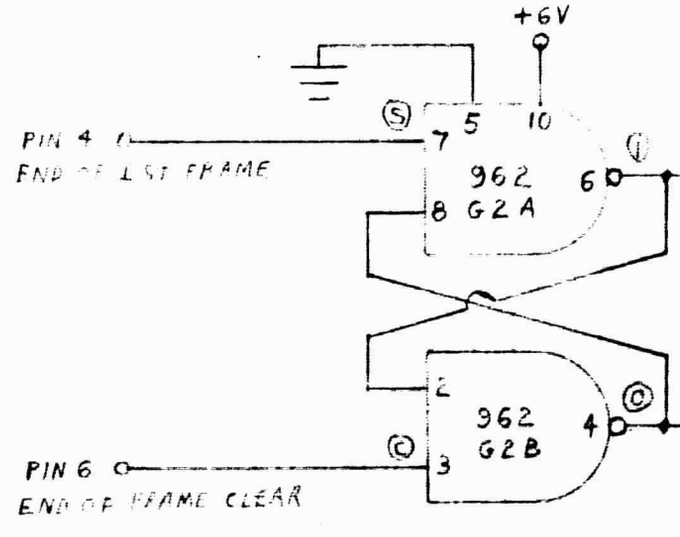

+16V
+10V
+6V
-16V
4.3K
62K
8.2K
6.2K
Q1
2N3640
1V
0V
-0.5V
10V
0V
1 MFD
+16V
-16V
MA709C
10K
1.5K
+6V
-16V
4.3K
3.9K
5.1K
8.2K
Q2
2N3640
0V
-10V
-0.6V
+6V
-16V
SW2
.005 MF
+10V
0V
35
-16V
6.2K
-10V
24K
5K
24K
+10V.
I.C. — START, END OF SWEEP
RASTER SWEEP PATTERN
+5V
0V
+6V
0V
35


+6V
G2B
-16V
+6V
-16V
10K
SWL
S8
HORIZ. SWP. IC.
-16V
10K
50pf
.1µf
EH
HORIZ. SWP
0V
-16V
1MEG
S
HORIZ. TRACE
S14
HORIZ. SWP. ACTIVATE, IC
OPEN TO OPERATE
PIN 5
10K
-16V
µA709C
EV
VERT SWP
680pf



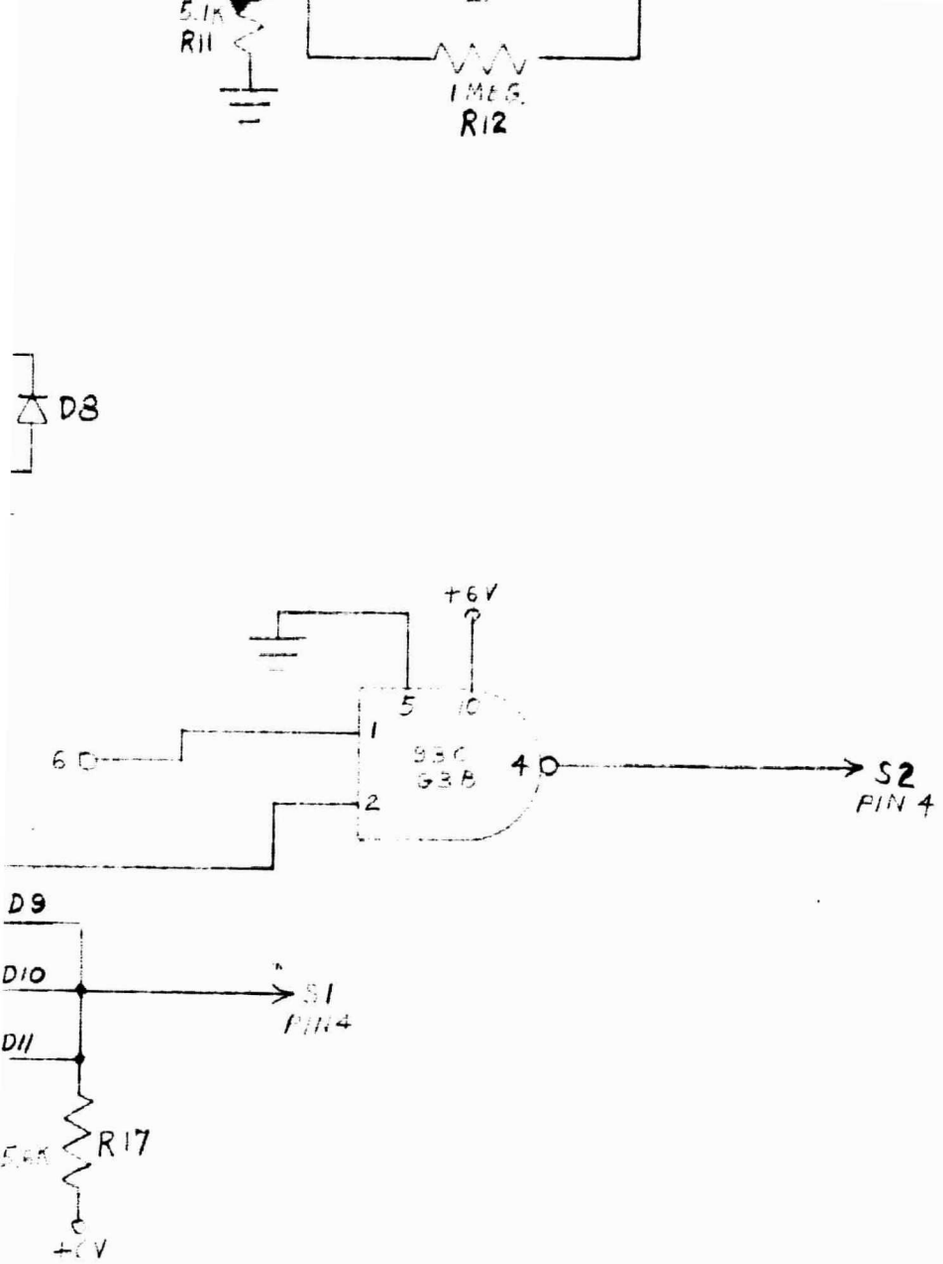


22	OPERATE
21	
20	
19	
18	
17	CLEAR
16	SIGNAL INPUT
15	+6V
14	+10V
13	+12V
12	+16V
11	GND
10	-16V
9	-10V
8	-6V
7	
6	ENL OF FRAME CLEAR
5	
4	END OF 1ST FRAME
3	
2	
1	OUTPUT



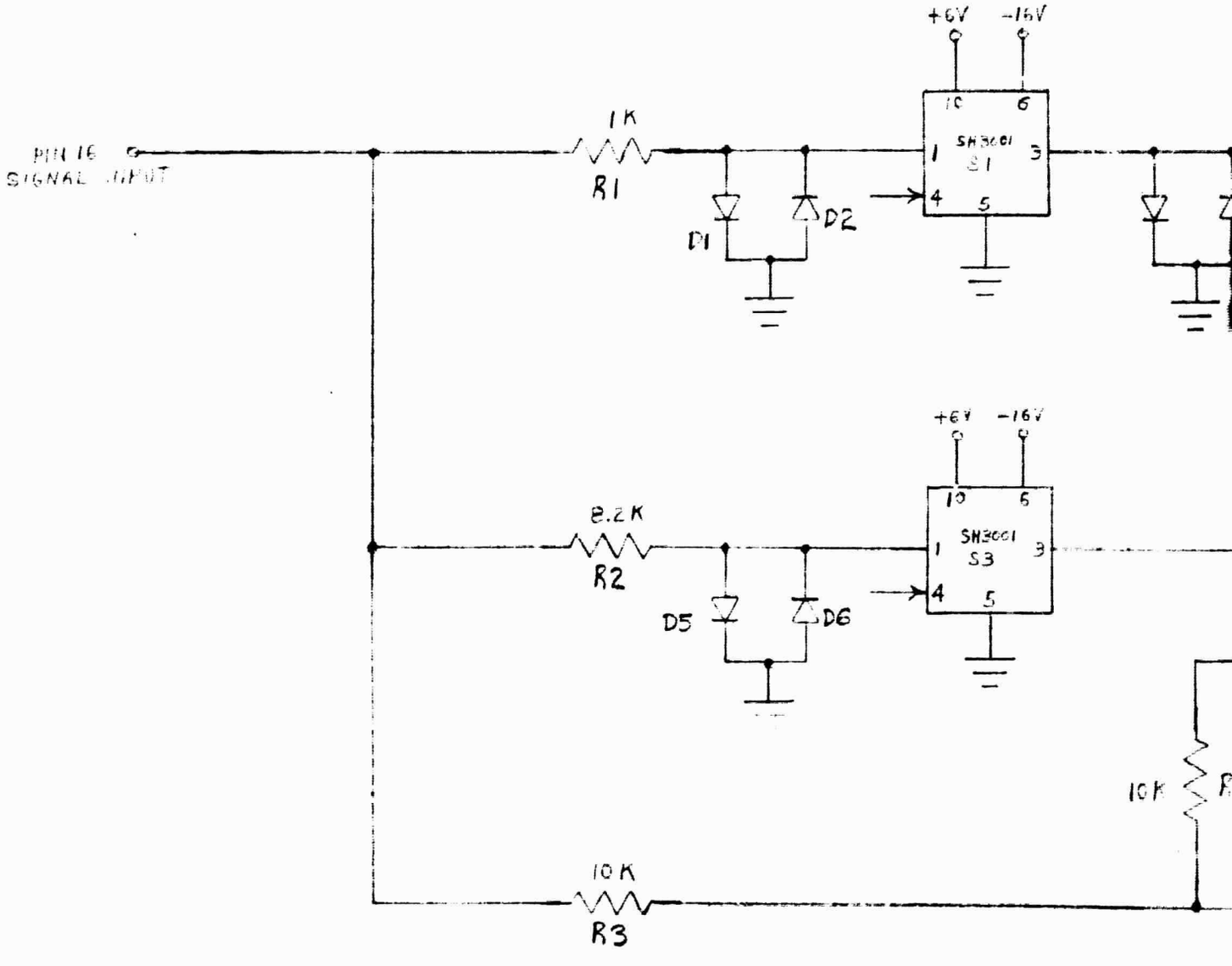
			SCALE	NONE
			PROJ. NO.	0114
			DRAWN BY	T. PATTIL
			DATE	4-2-6
			FOR ASSEMBLY	
			MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

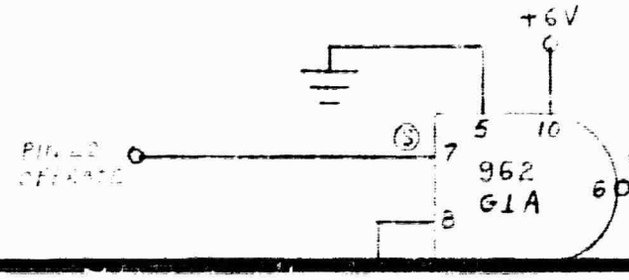
II

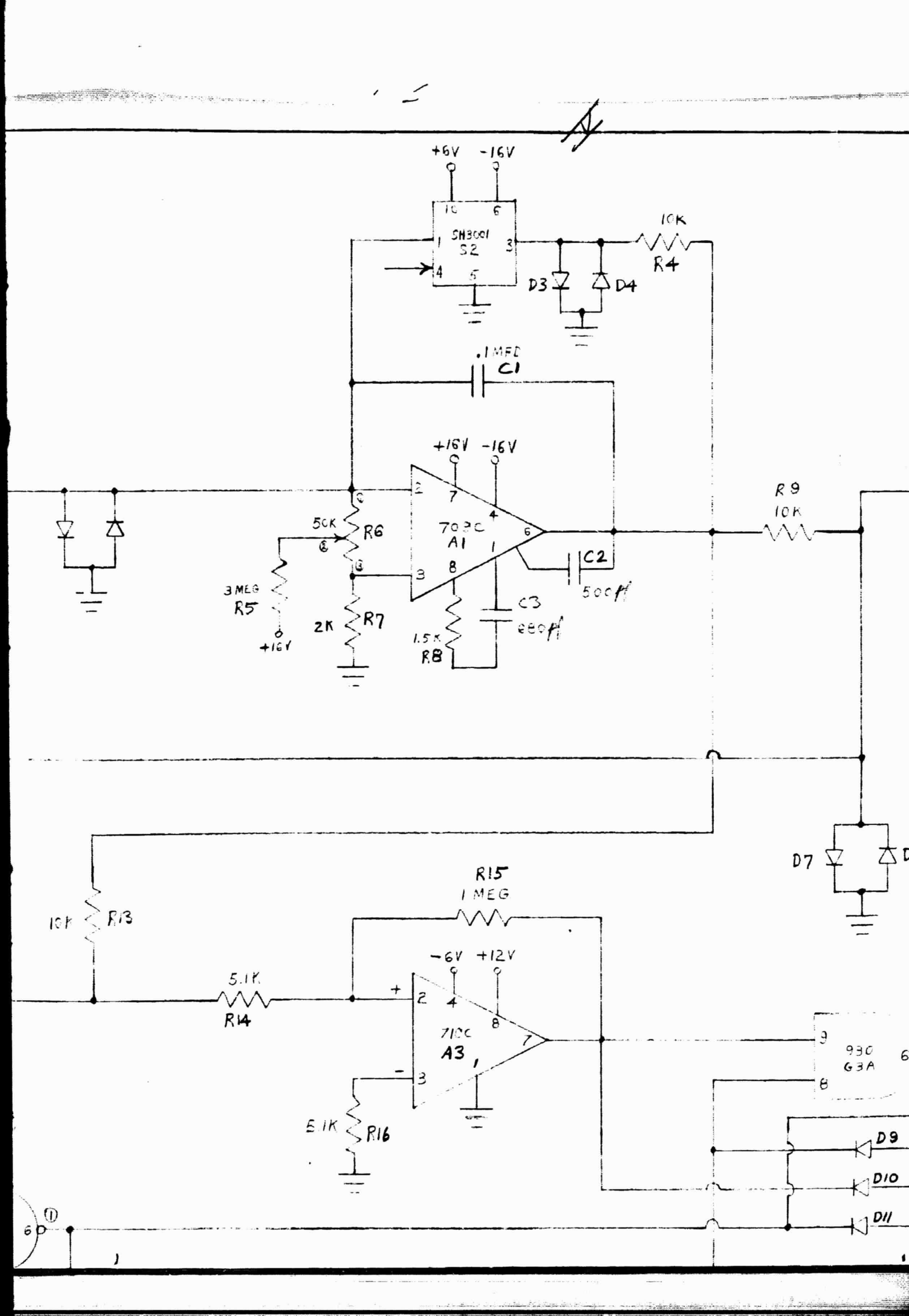


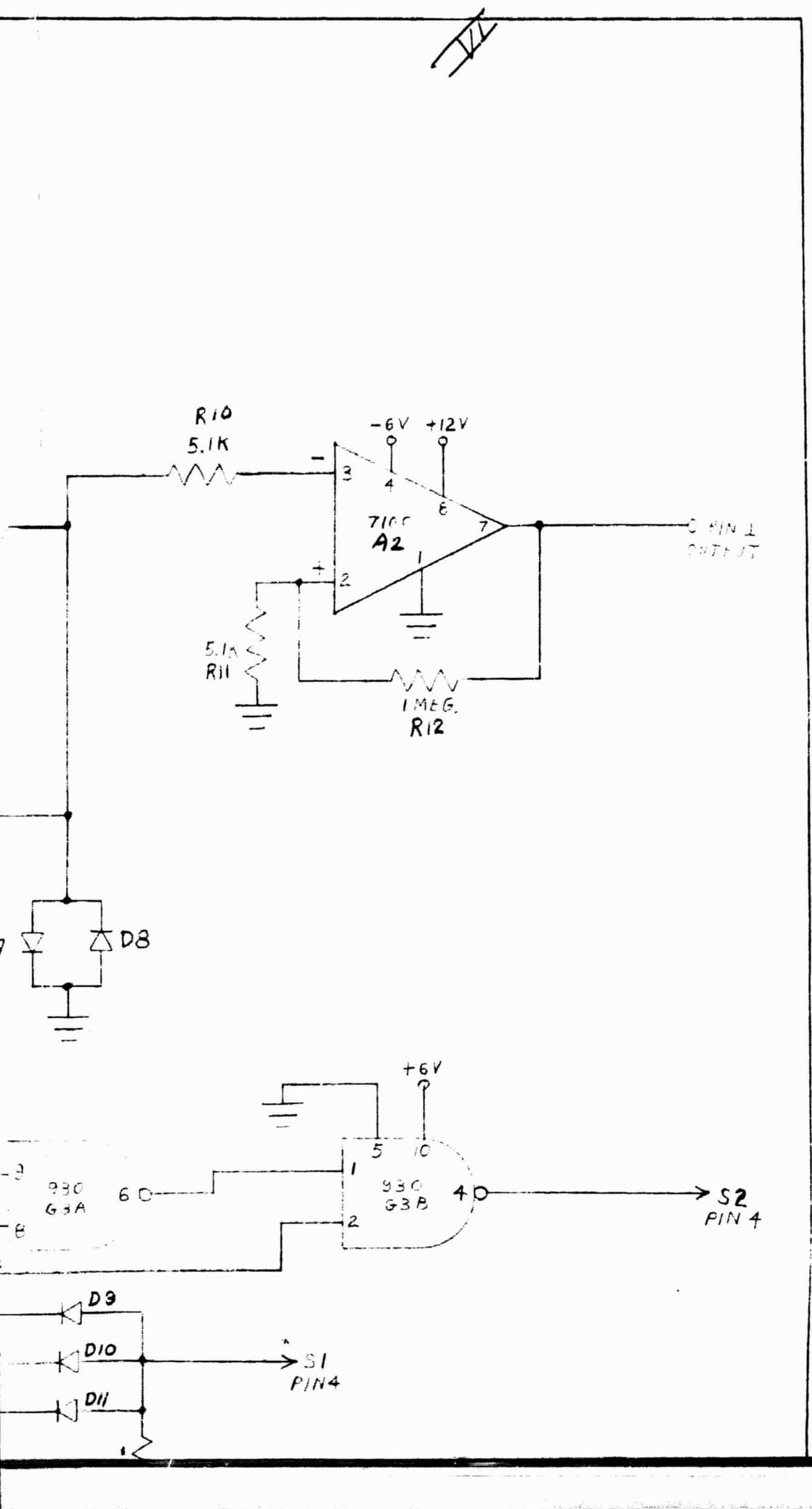
NOTES:
1. ALL RESISTORS 1/4 W 5% UNLESS NOTED
2. ALL DIODES ARE IN4688

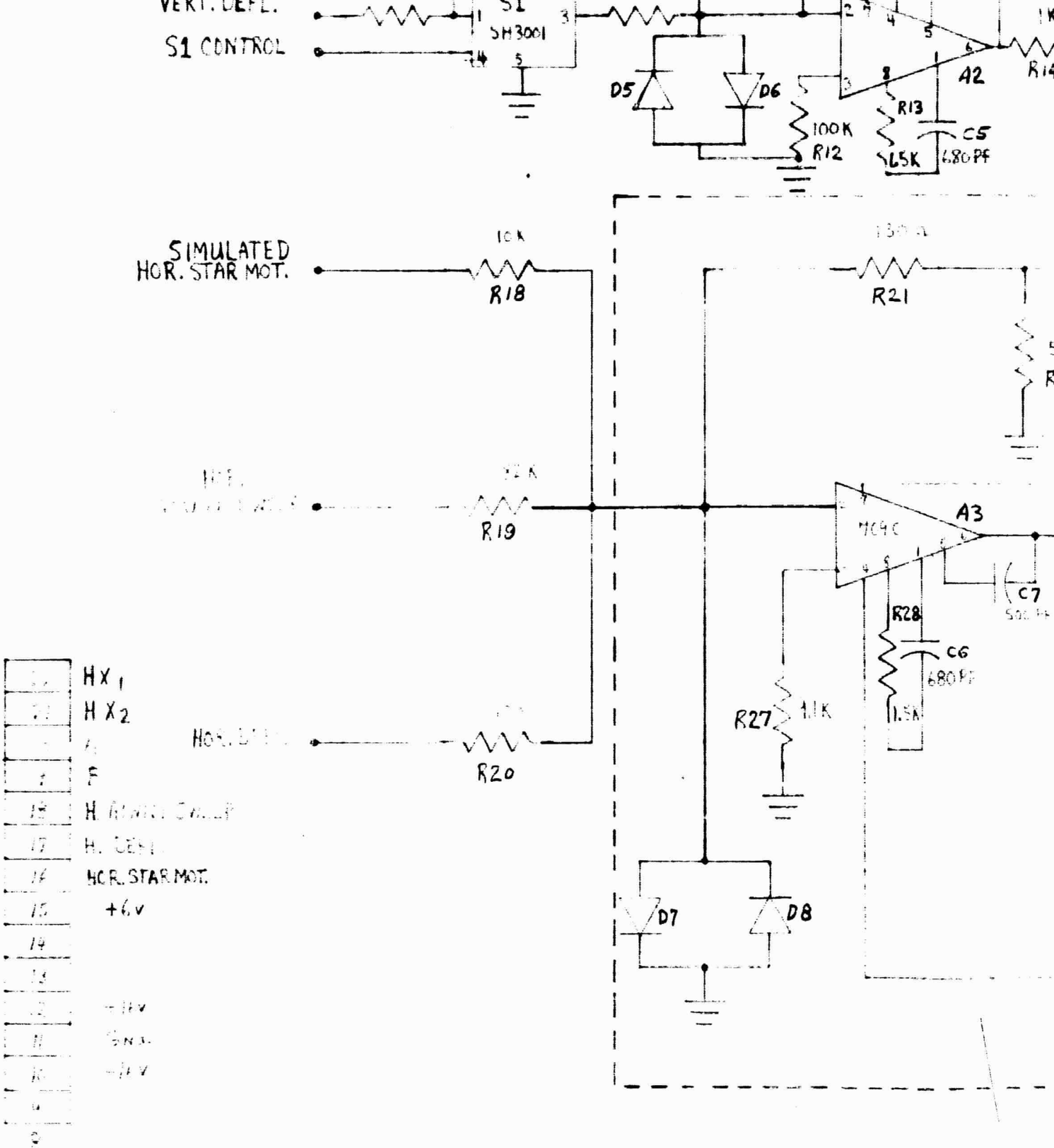
NE 114 TTISON -2-68	**HIGH ALTITUDE ENGINEERING LABORATORY** **UNIVERSITY OF MICHIGAN** **DEPARTMENT OF AERO. AND ASTRO. ENGINEERING** **ANN ARBOR MICHIGAN**
	NAME PEAK LIGHT INTENSITY HOLD DETECTOR
	DRAWING NO. H3-52016


+6V
-16V
1K
R1
PULSE
SIGNAL INPUT
D1
D2
10
6
SH3001
S1
1
3
4
5
8.2K
R2
D5
D6
S3
10K
R3

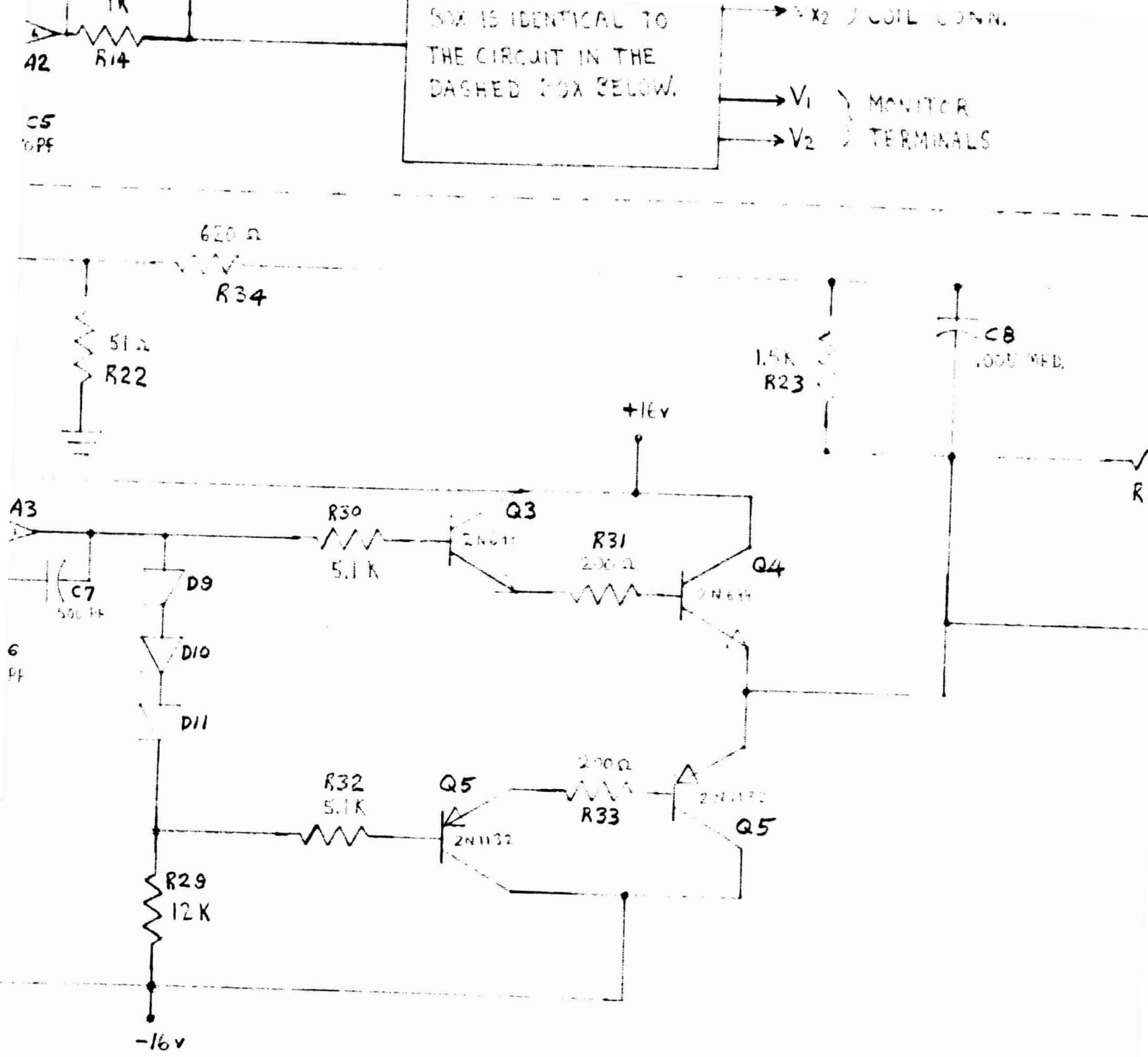

+6V
5
10
7
962
G1A
6
8


+6V
-16V
SN3001
S2
10K
R4
D3
D4
.1 MFD
C1
+16V
-16V
709C
A1
50K
R6
3 MEG
R5
+16V
2K
R7
1.5K
R8
C3
C2
500pf
R9
10K
D7
R15
1 MEG
10K
R13
-6V
+12V
5.1K
R14
710C
A3
5.1K
R16
930
G3A
D9
D10
D11

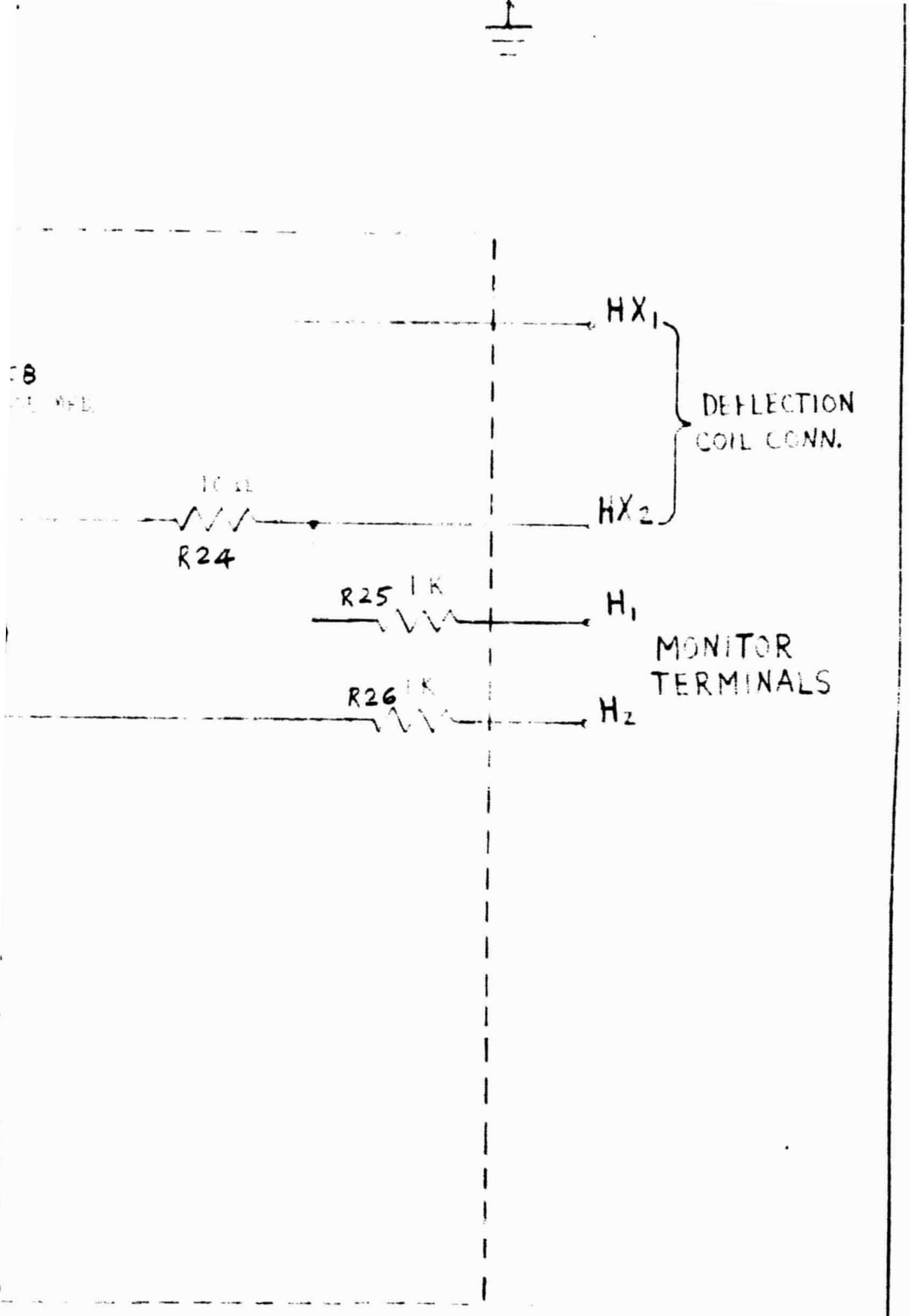

R10
5.1K
-6V
+12V
3
4
8
7
2
1
7106
A2
PIN 1
OUTPUT
5.1K
R11
1 MEG.
R12
D8
+6V
5
10
1
2
930
G3A
930
G3B
6
4
S2
PIN 4
D9
D10
D11
S1
PIN4



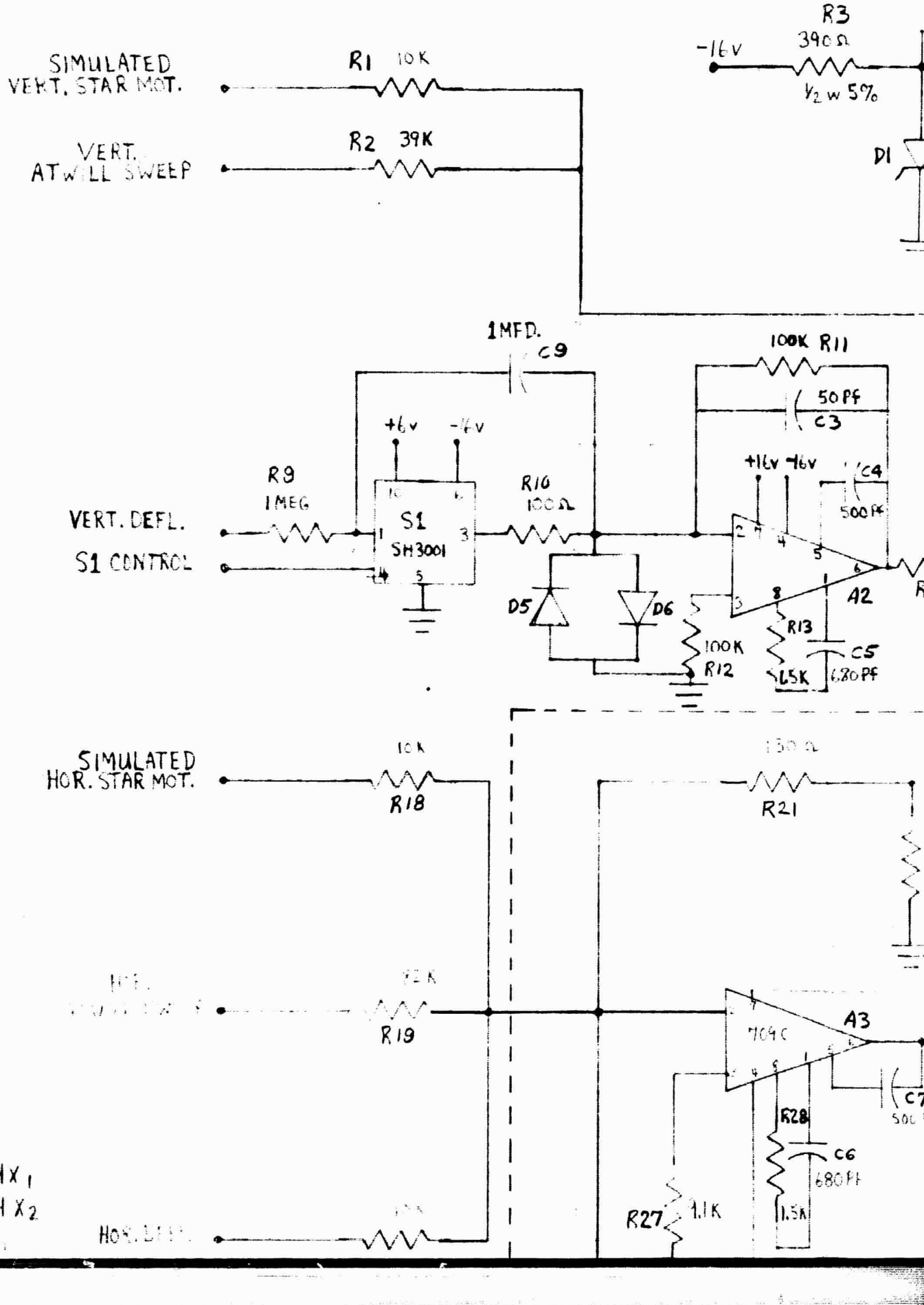
ALL DIODES ARE IN486B UNLESS NOTED
ALL RESISTORS ARE 1/4W 5% UNLESS NOTED

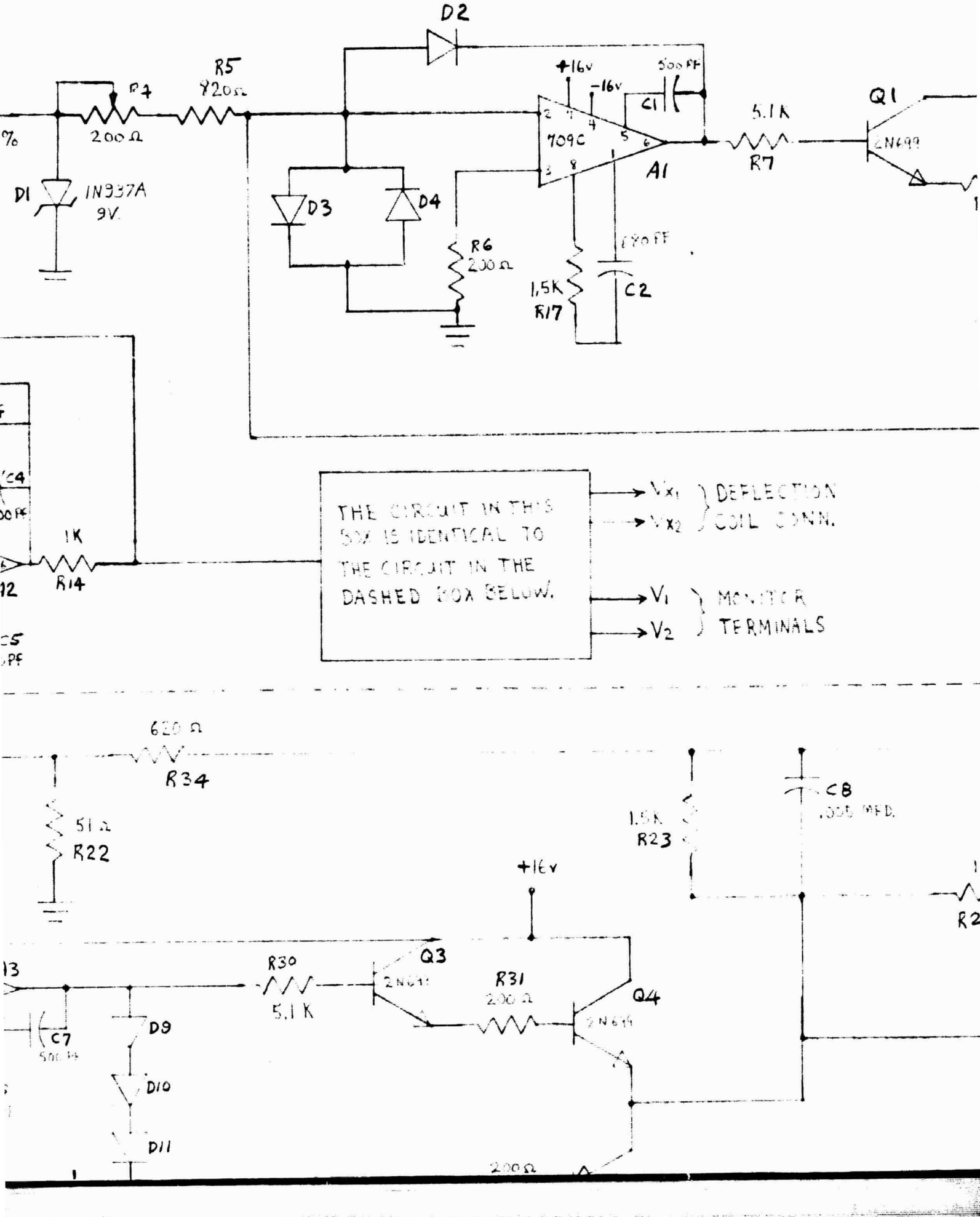


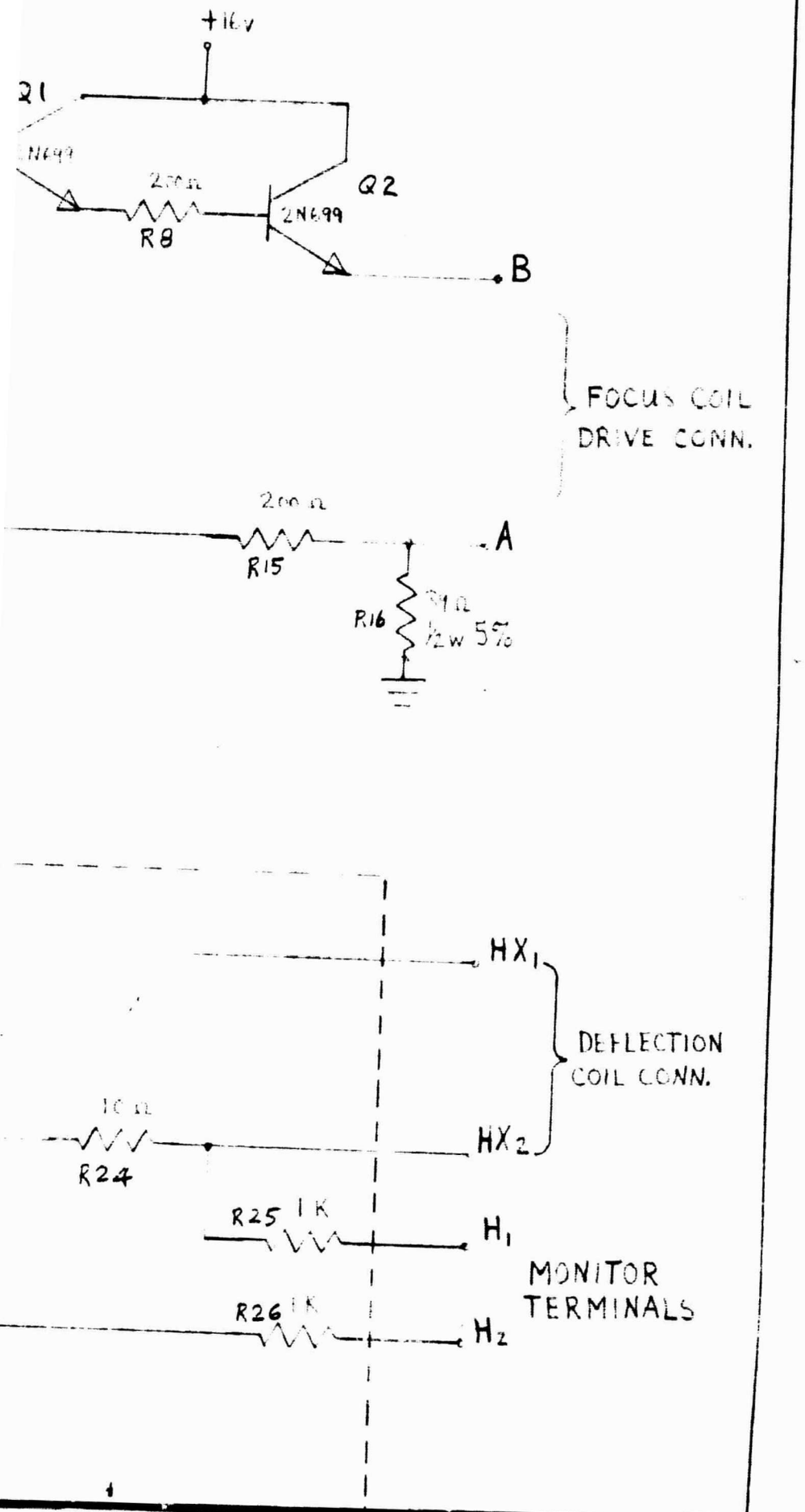
			SCALE	NONE
			PROJ. NO.	01114
			DRAWN BY	E. GILREATH
			DATE	4-2-68
			FOR ASSEMBLY	
			MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

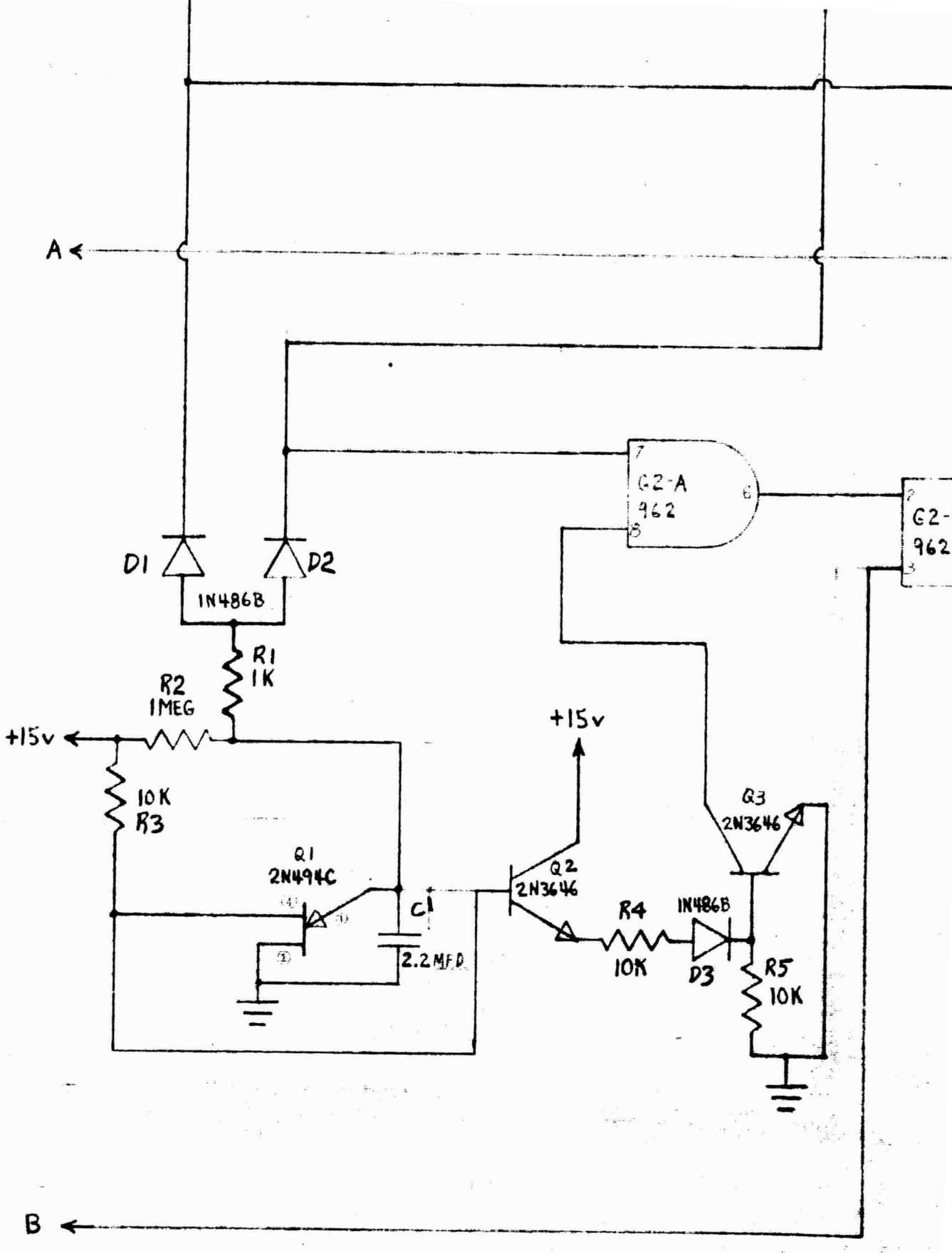


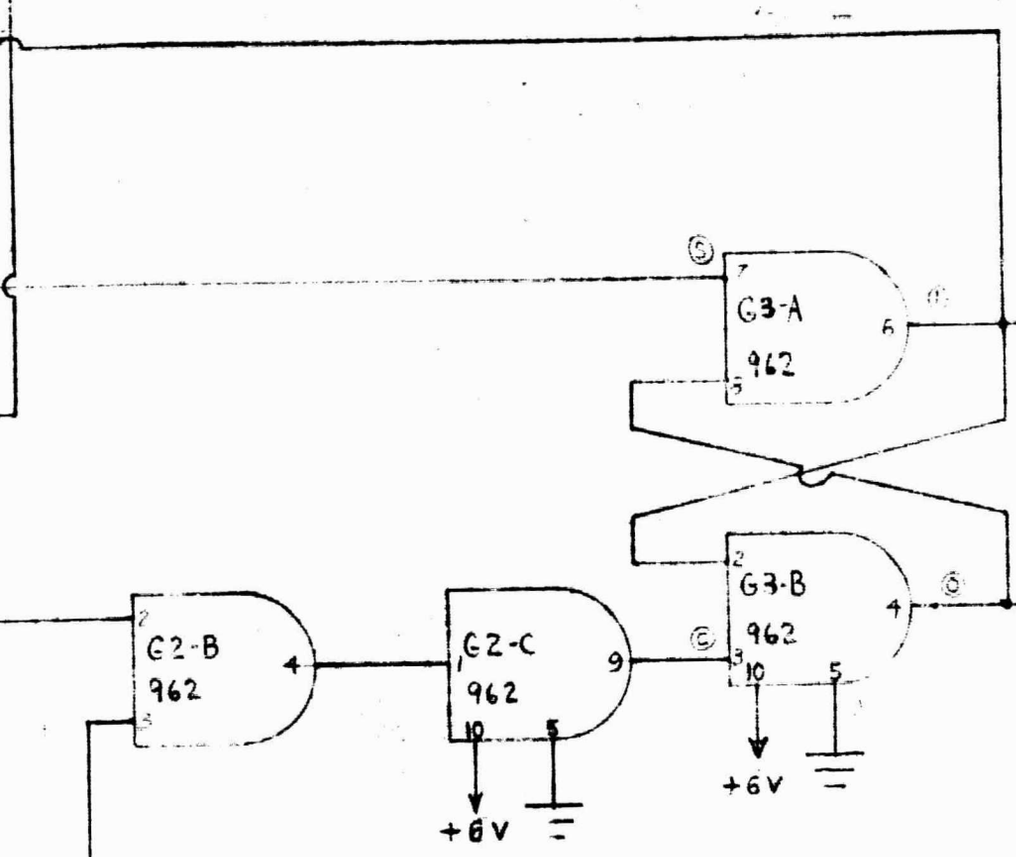
	HIGH ALTITUDE ENGINEERING LABORATORY **UNIVERSITY OF MICHIGAN** ***DEPARTMENT OF AERO. AND ASTRO. ENGINEERING*** **ANN ARBOR MICHIGAN**
	NAME FOCUS REGULATOR AND DEFLECTION COIL DRIVERS
	DRAWING NO. H3-52017


SIMULATED
VERT. STAR MOT.
R1 10K
VERT.
ATWILL SWEEP
R2 39K
-16v
R3
390Ω
½ w 5%
D1
1MFD.
C9
100K R11
50 Pf
C3
+16v -16v
C4
500 Pf
R9
1 MEG
R10
100Ω
VERT. DEFL.
S1 CONTROL
S1
SH3001
D5
D6
A2
100K
R12
R13
6.5K
C5
680 Pf
SIMULATED
HOR. STAR MOT.
10K
R18
R21
R19
A3
7094
R28
C6
680 Pf
R27
1.1K
1.5K
HX1
HX2


D2
R5
720Ω
R4
200Ω
+16V
-16V
500 PF
C1
709C
A1
5.1K
R7
Q1
2N699
D1
IN937A
9V.
D3
D4
R6
200Ω
1,5K
R17
C2
1K
R14
THE CIRCUIT IN THIS BOX IS IDENTICAL TO THE CIRCUIT IN THE DASHED BOX BELOW.
DEFLECTION COIL CONN.
MONITOR TERMINALS
620Ω
R34
51Ω
R22
1.5K
R23
C8
.005 MFD.
+16V
R30
5.1K
Q3
2N699
R31
200Ω
Q4
2N699
C7
500 PF
D9
D10
D11
200Ω

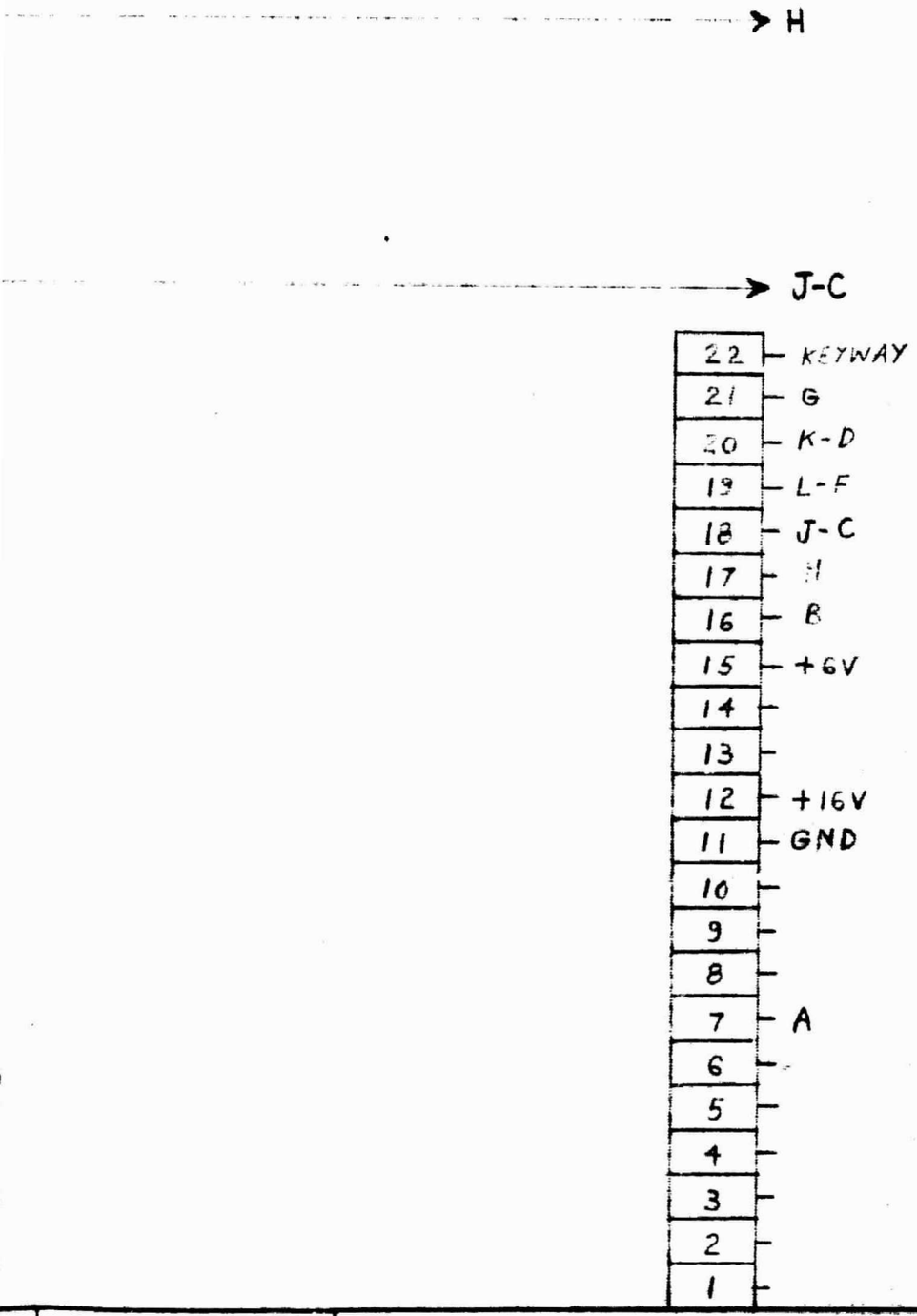

+16v
Q1
2N699
270Ω
R8
Q2
2N699
B
FOCUS COIL
DRIVE CONN.
200Ω
R15
A
R16
91Ω
½w 5%
HX1
DEFLECTION
COIL CONN.
10Ω
R24
HX2
R25 1K
H1
MONITOR
TERMINALS
R26 1K
H2


A
G2-A
962
G2-
962
D1
D2
1N486B
R1
1K
R2
1MEG
+15v
10K
R3
Q1
2N494C
C1
2.2 MFD
+15v
Q2
2N3646
Q3
2N3646
R4
10K
1N486B
D3
R5
10K
B



NOTES:
1. ALL RESISTORS ¼W, 5%

			SCALE	NONE
			PROJ. NO.	01114
			DRAWN BY	ED GILREAT TED PATTI
			DATE	4-5-6
			FOR ASSEMBLY	
			MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	



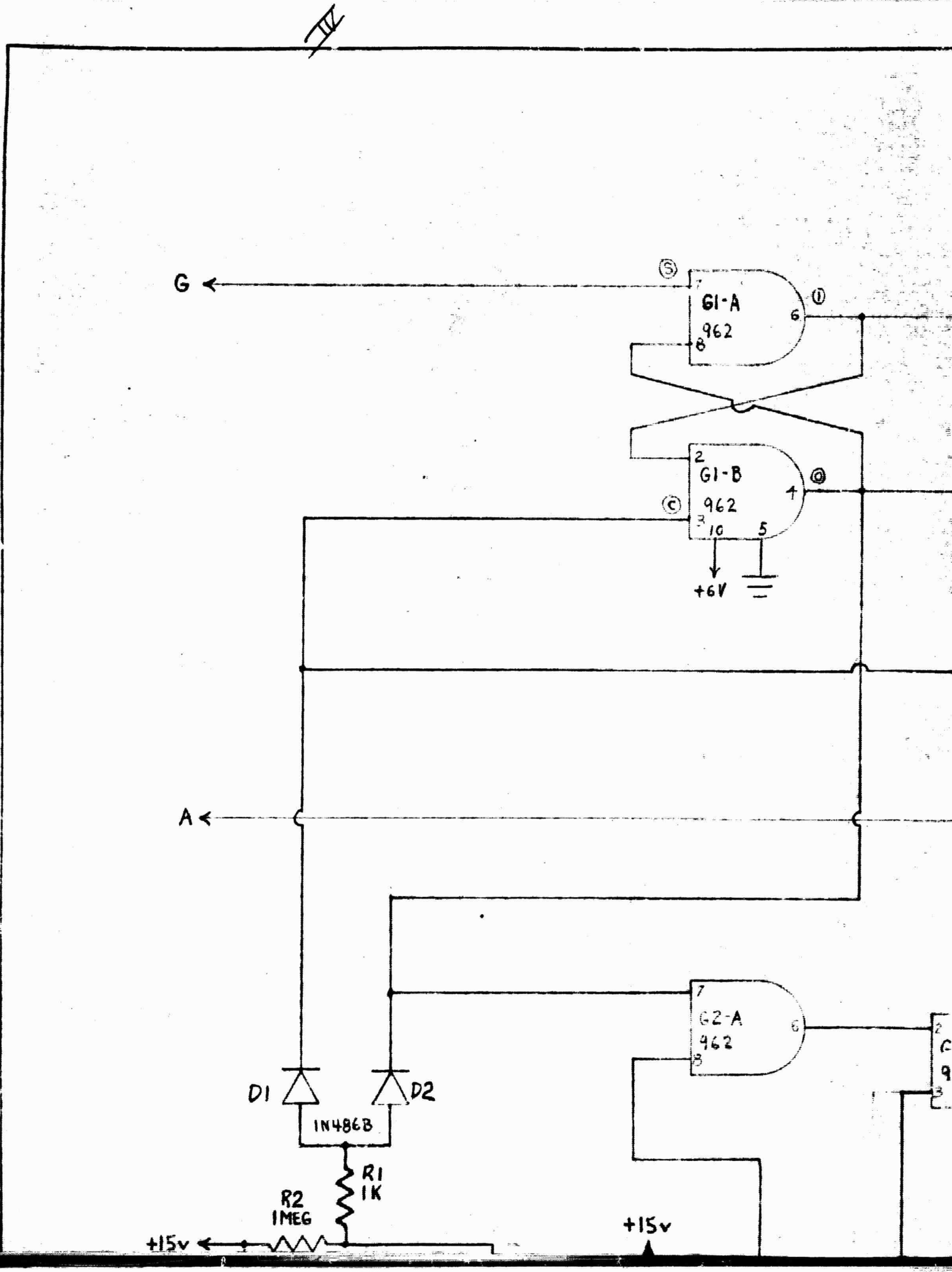
	NONE
	01114
	ED GILREATH TED PATTINSON
	4-5-68

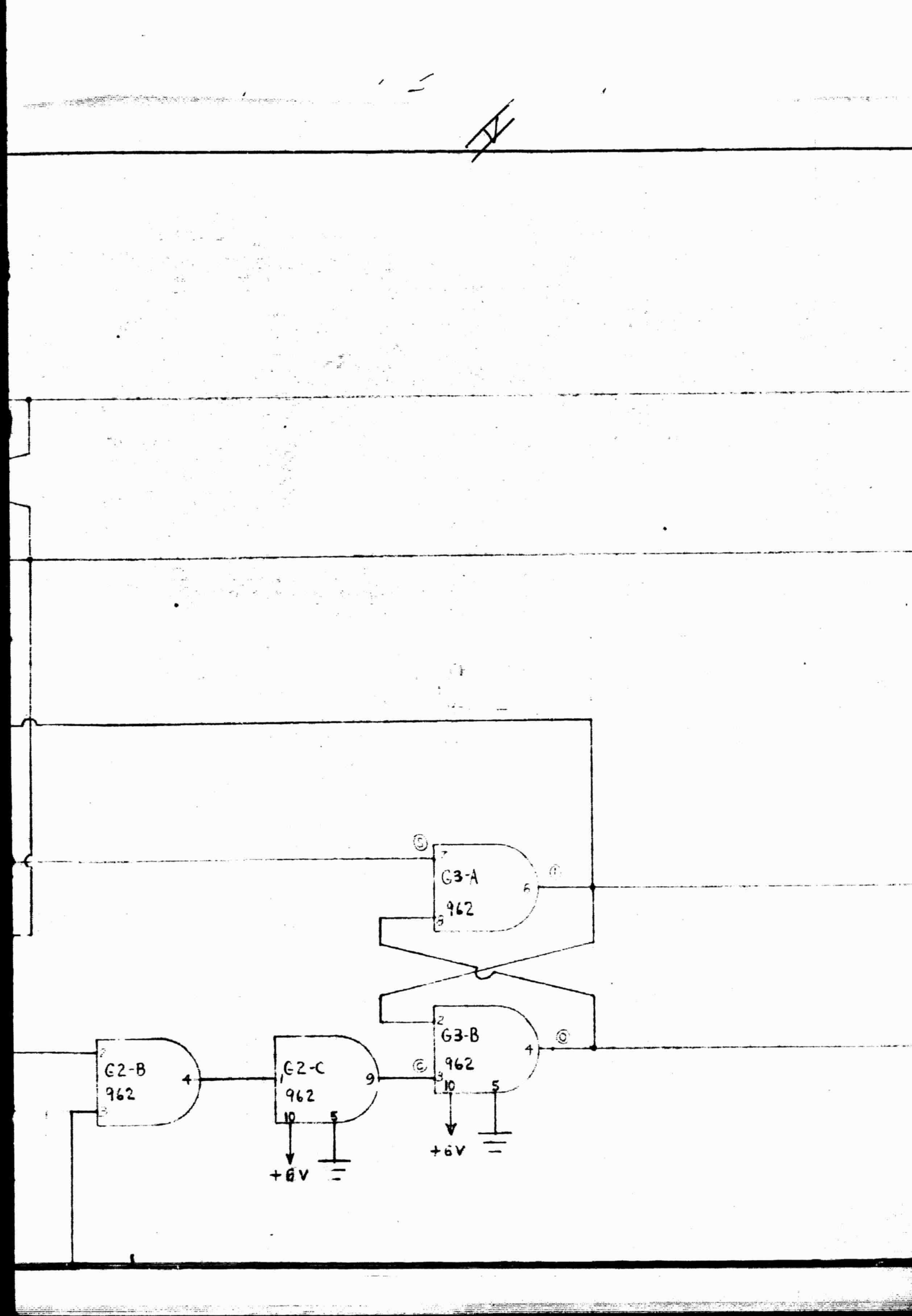
HIGH ALTITUDE ENGINEERING LABORATORY
UNIVERSITY OF MICHIGAN
DEPARTMENT OF AEROSPACE ENGINEERING
ANN ARBOR MICHIGAN

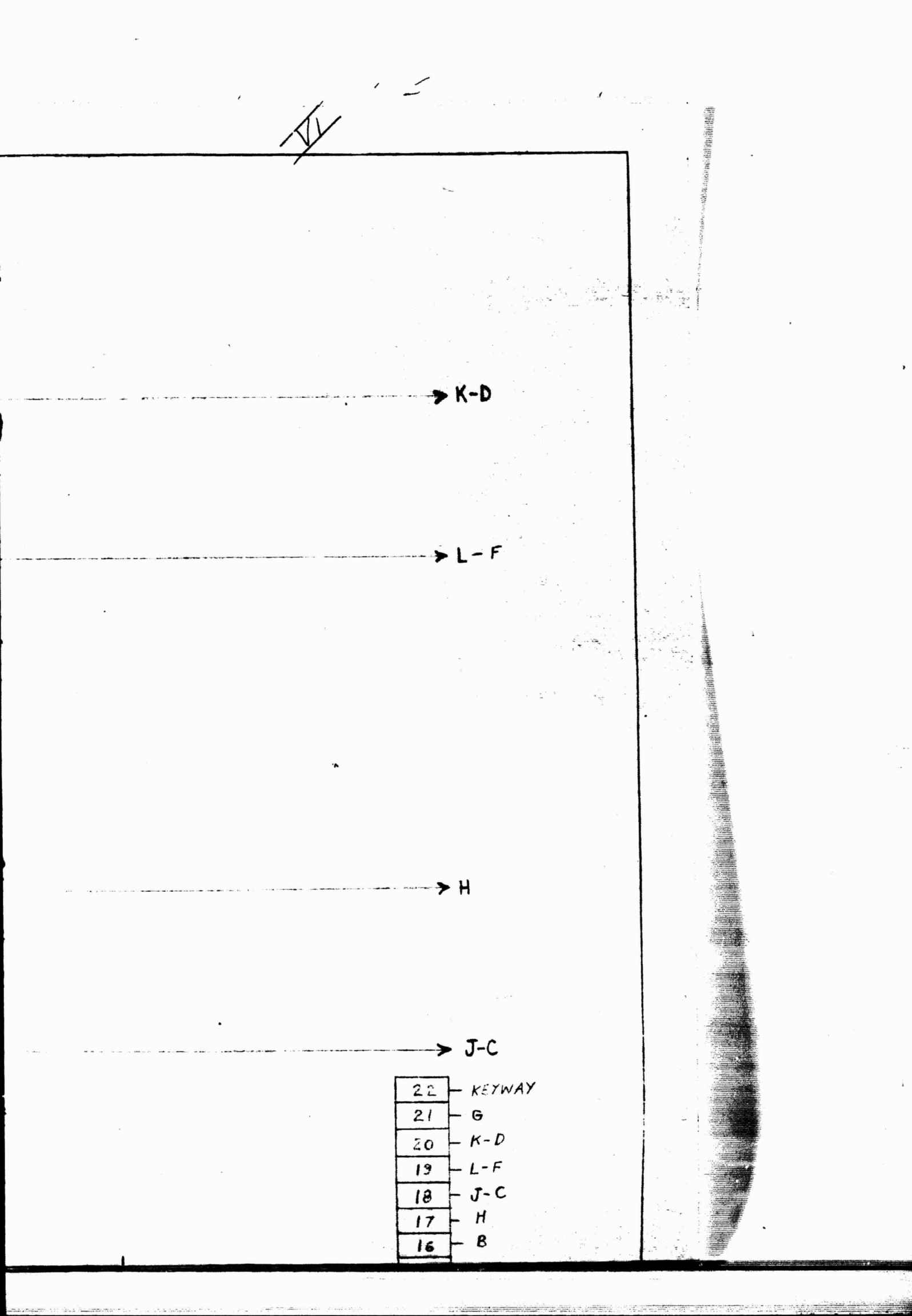
NAME DATA TELESCOPE LOGIC CARD

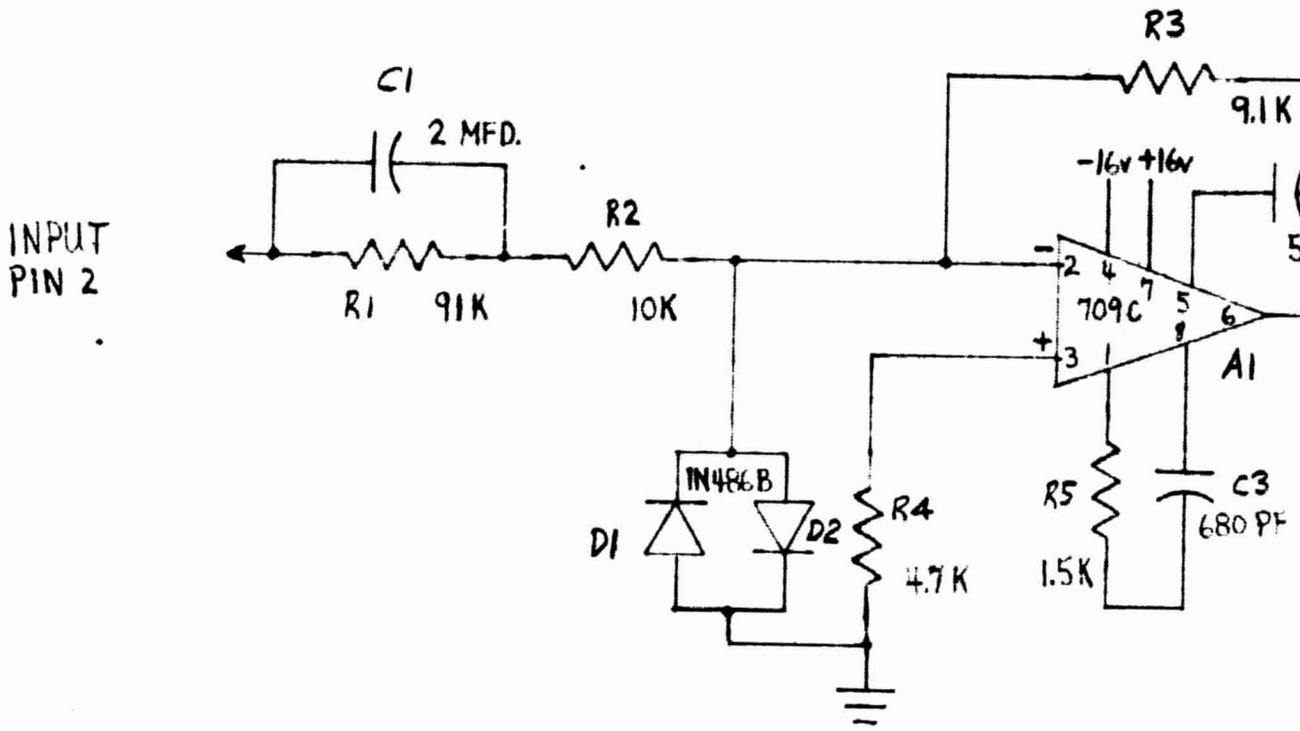
DRAWING NO. H3-52018

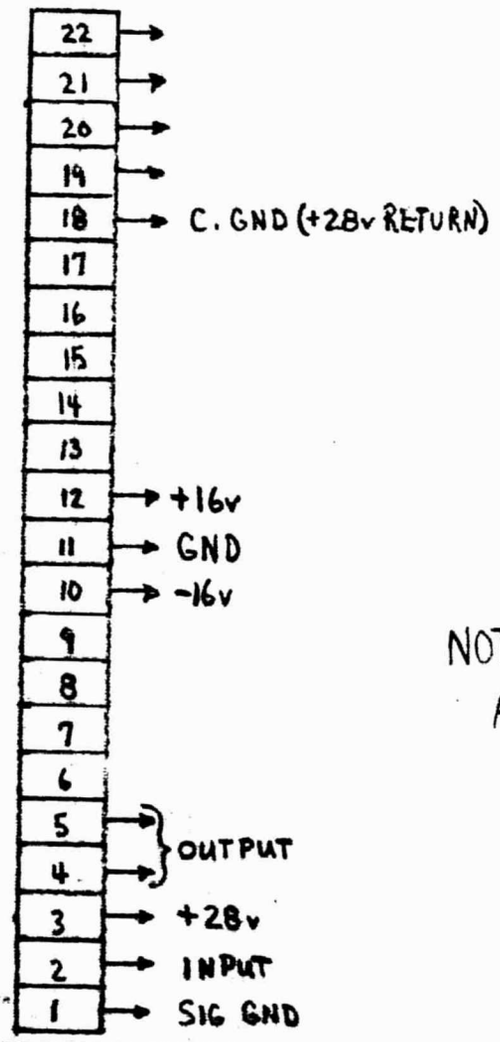
III


G
G1-A
962
G1-B
962
+6V
A
G2-A
962
D1
D2
IN486B
R1
1K
R2
1MEG
+15v
+15v

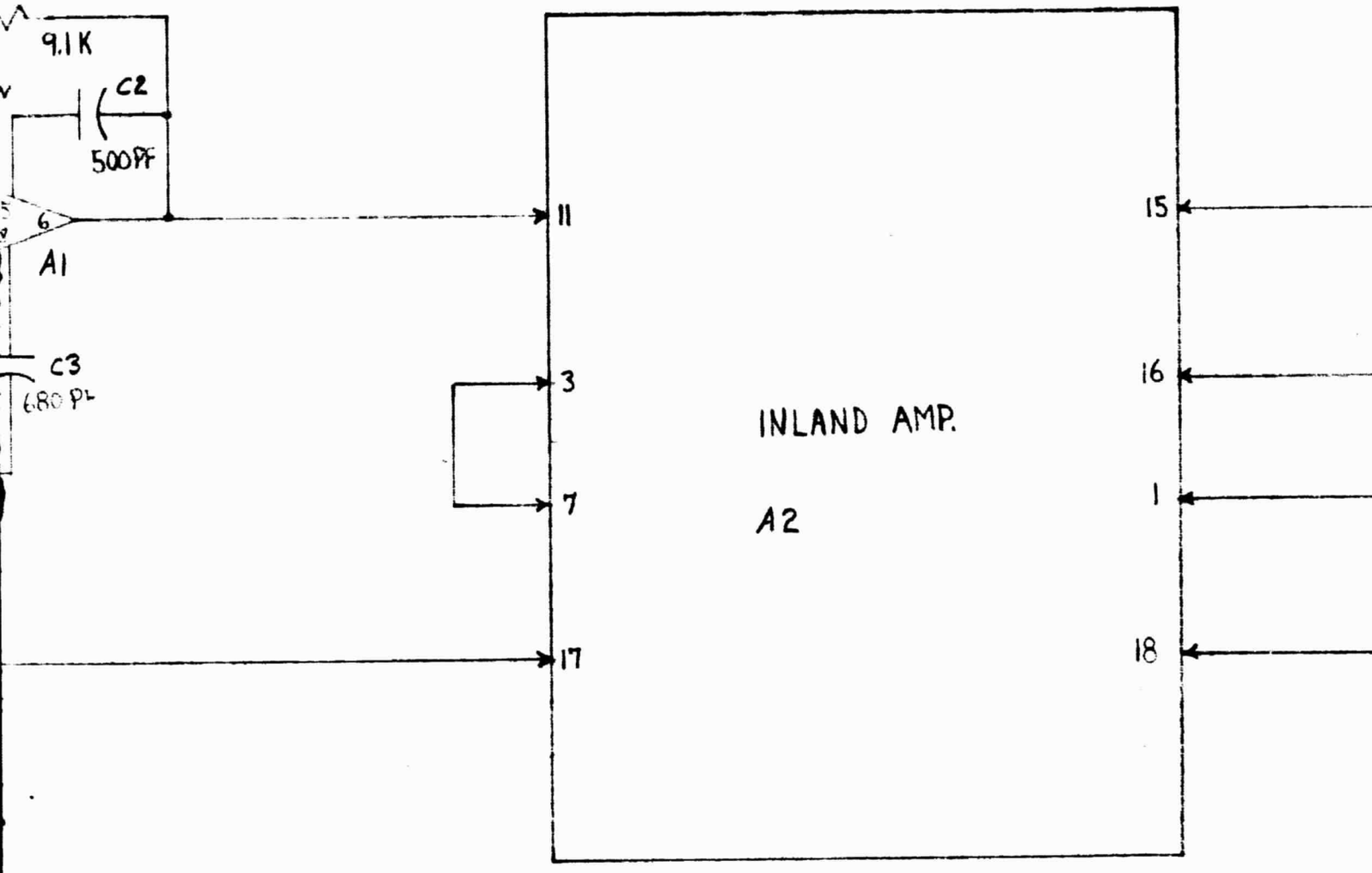

G3-A
962
G3-B
962
G2-B
962
G2-C
962
+6V
+6V


K-D
L-F
H
J-C
22 KEYWAY
21 G
20 K-D
19 L-F
18 J-C
17 H
16 B

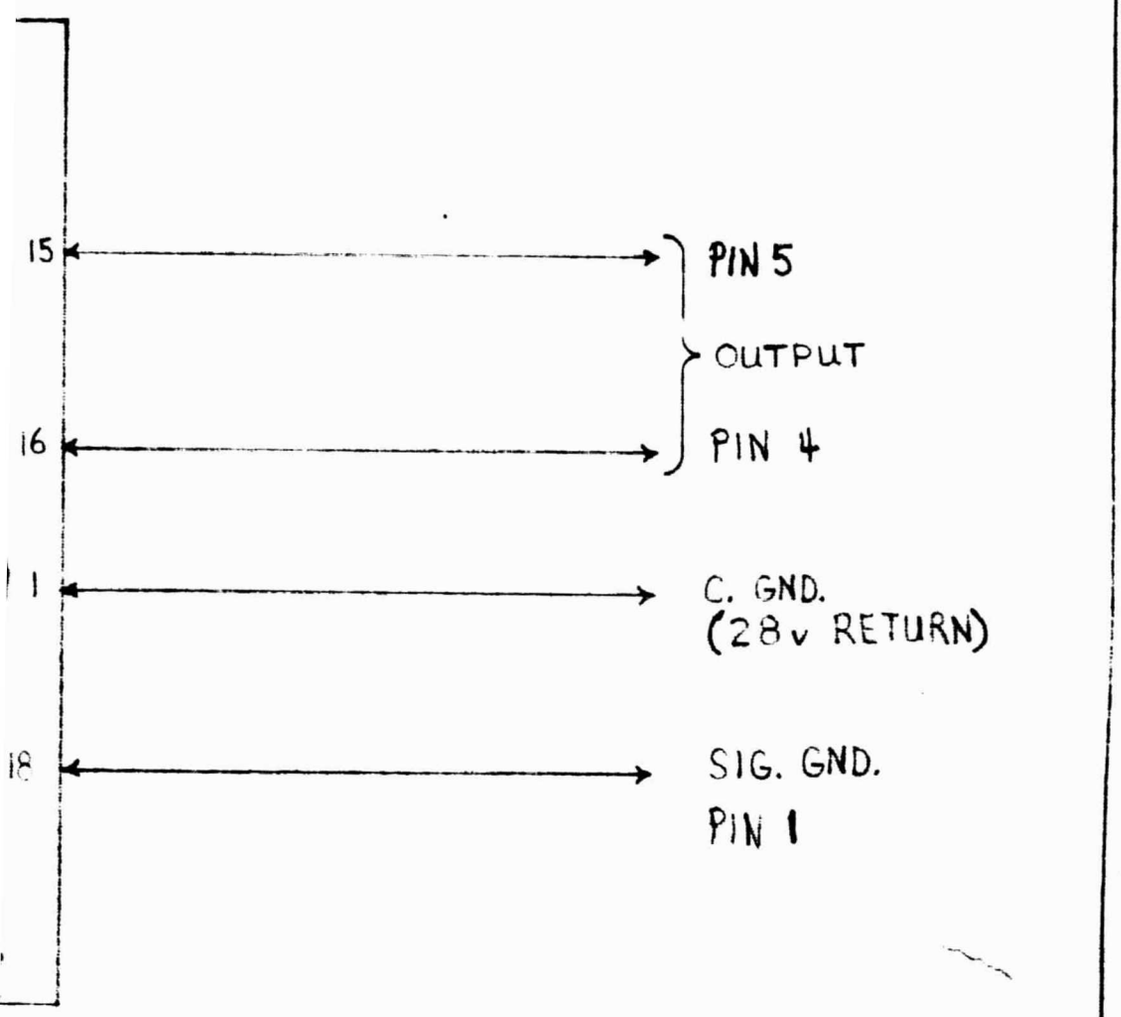




NOTE:
ALL RESISTORS ¼w 5% UNLESS NOTED.

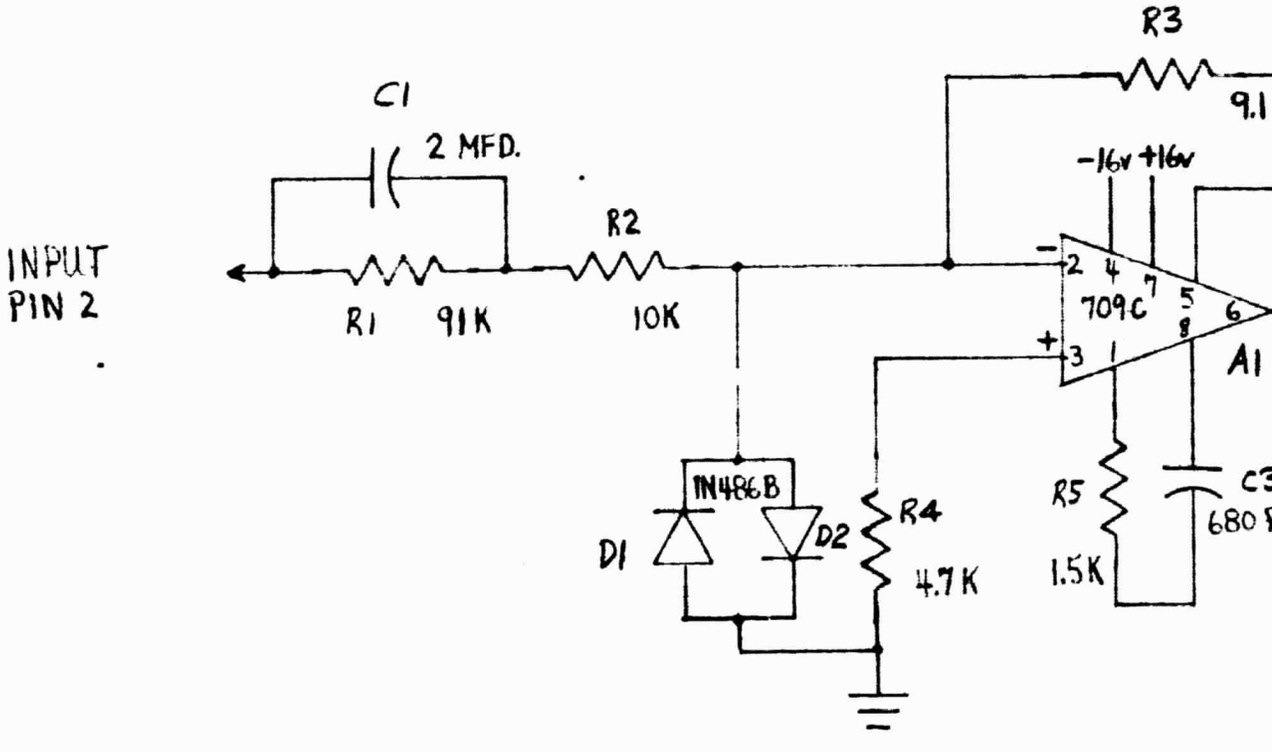


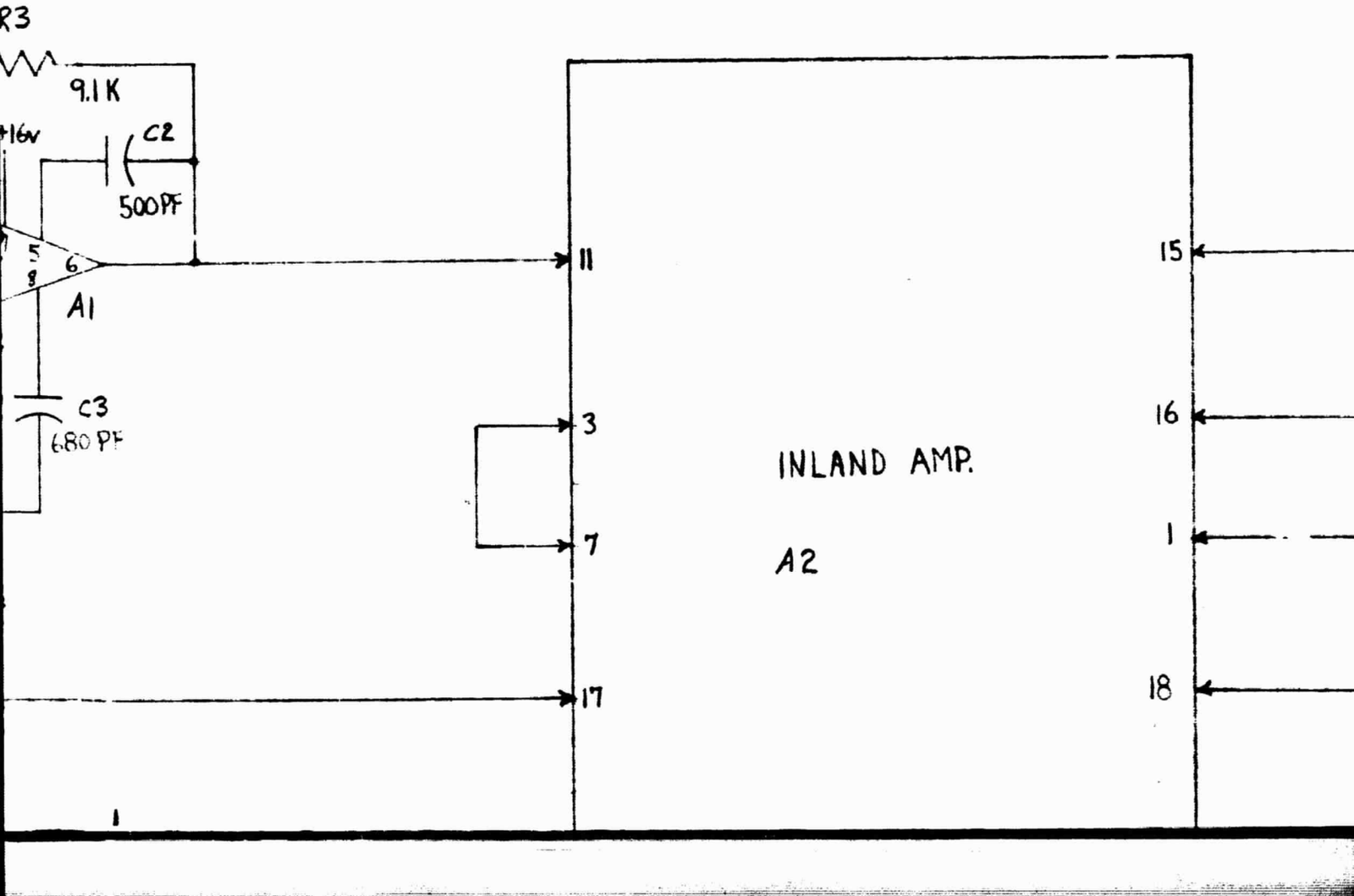
			SCALE	
			PROJ. NO.	
			DRAWN BY	E. M. [illegible]
			DATE	APRIL 15 1968
			FOR ASSEMBLY	
			MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	



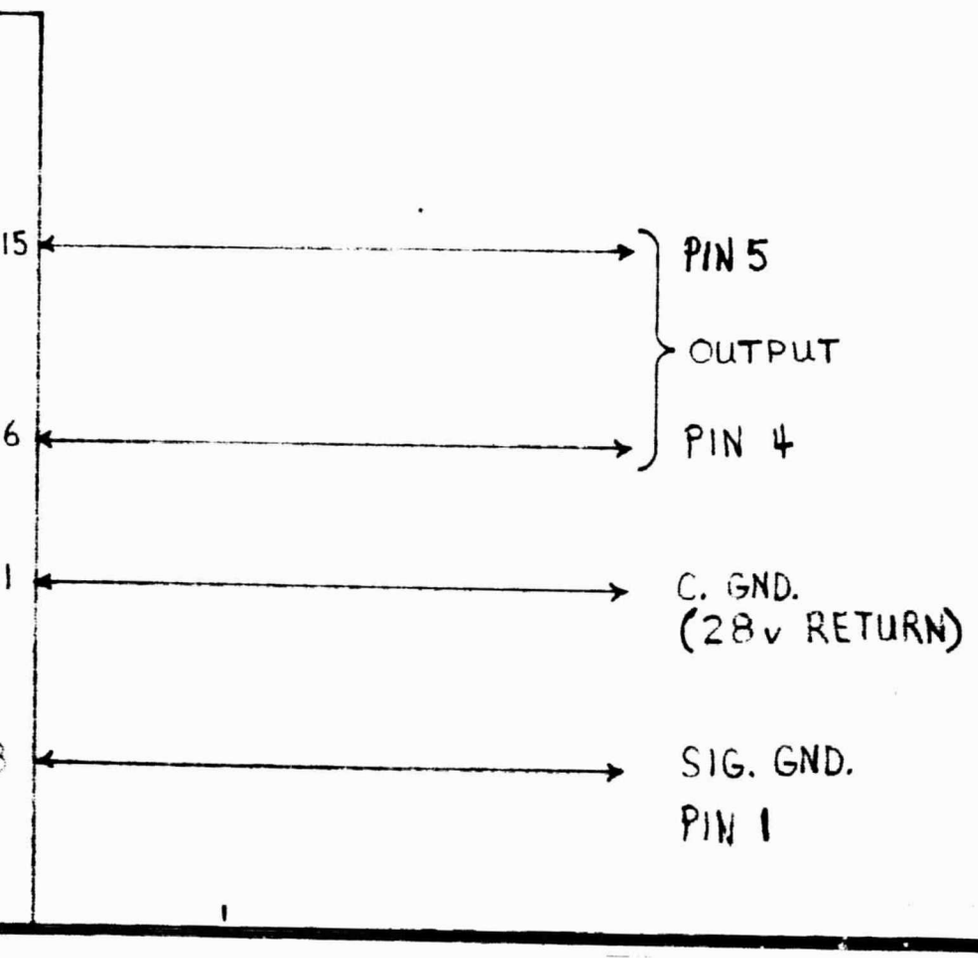
	HIGH ALTITUDE ENGINEERING LABORATORY UNIVERSITY OF MICHIGAN DEPARTMENT OF AEROSPACE ENGINEERING ANN ARBOR MICHIGAN
APRIL 15 1968	NAME TORQUE MOTOR DRIVE AMP.
	DRAWING NO. H3-52021

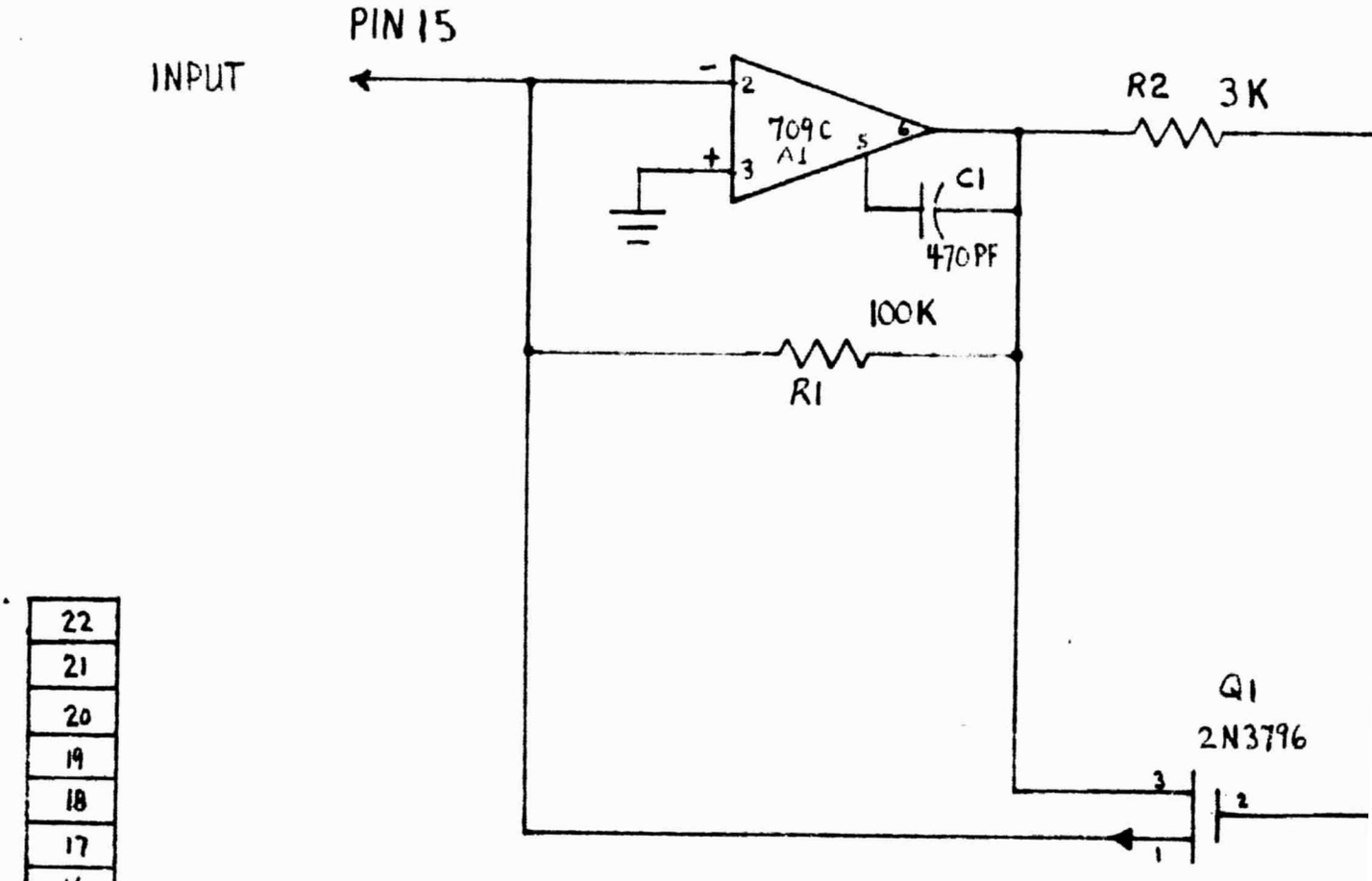
IV

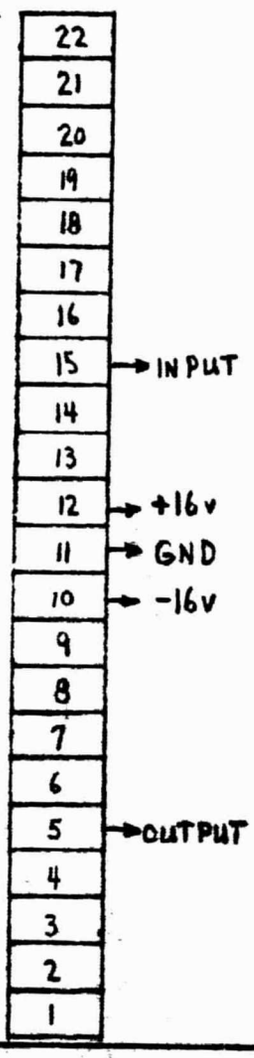

R3
9.1
C1
2 MFD.
-16v +16v
R2
INPUT
PIN 2
R1 91K
10K
2 4 7 5 6
709C
8
3 1
A1
IN486B
D1
D2
R4
4.7K
R5
1.5K
C3
680
+28 v
PIN 3

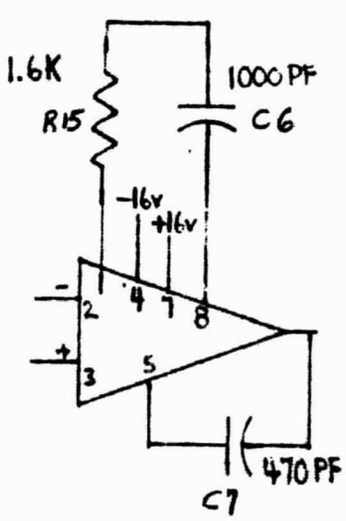

R3
9.1 K
+16v
C2
500PF
5
8
6
A1
C3
680 PF
11
3
7
17
INLAND AMP.
A2
15
16
1
18
1

VI





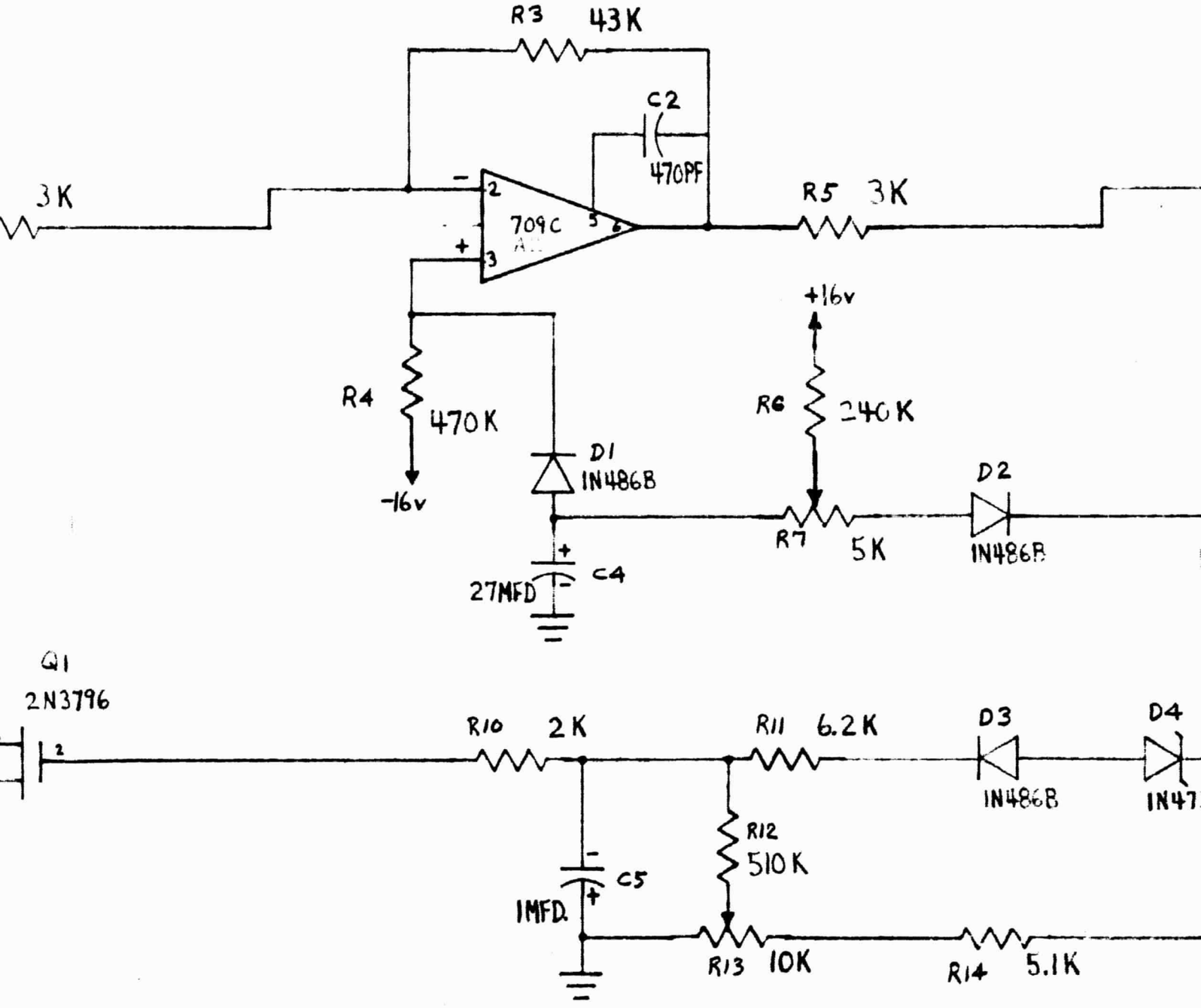




TYPICAL AMP. CONNECTIONS

ALL RESISTORS 1/4 w 5% UNL

I

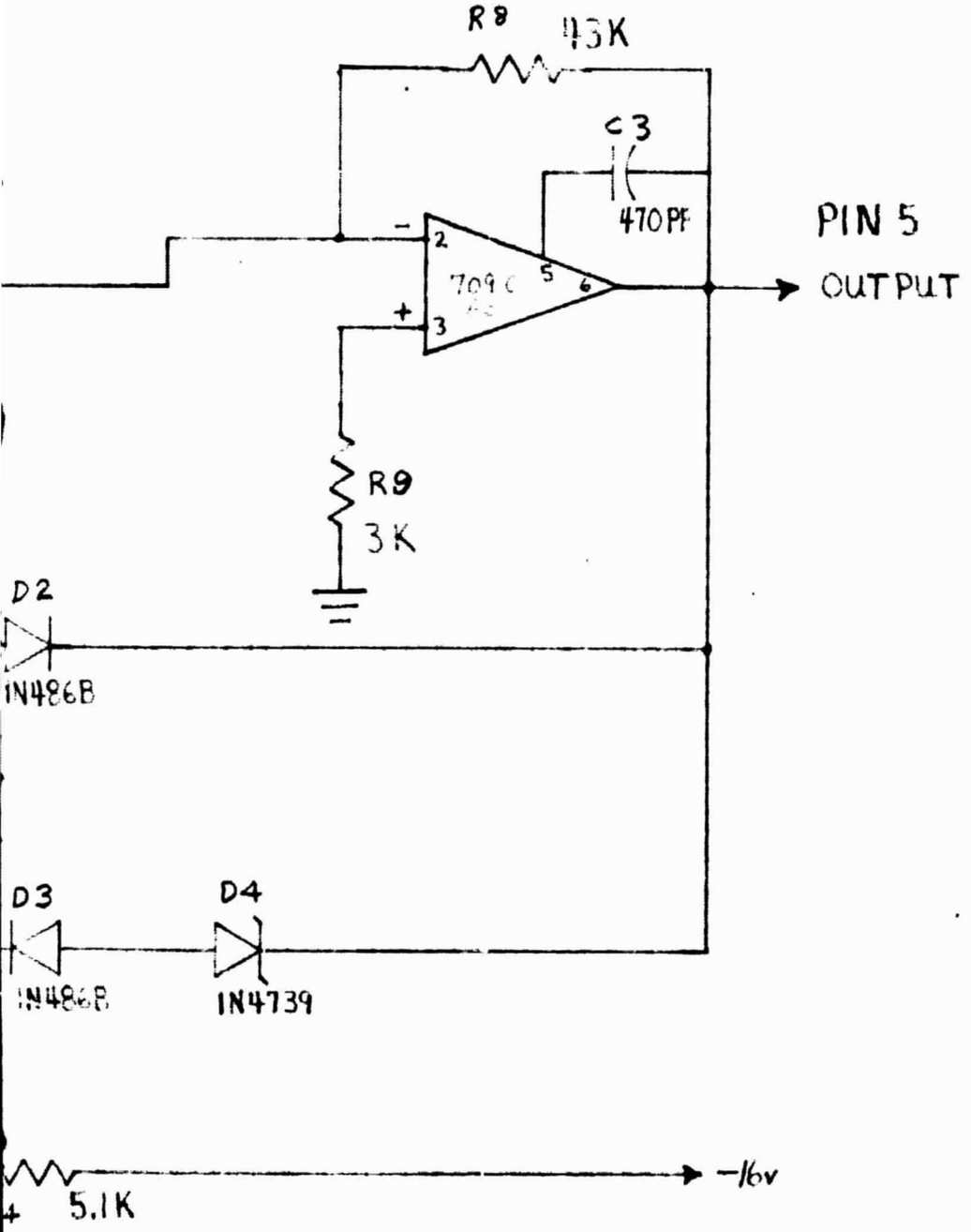


ECTIONS

w 5% UNLESS NOTED

			SCALE	
			PROJ. NO.	01114
			DRAWN BY	
			DATE	4-15-1968
			FOR ASSEMBLY	
			MATERIAL	
---	CHANGE	DATE	WEIGHT CAL ACT.	

1

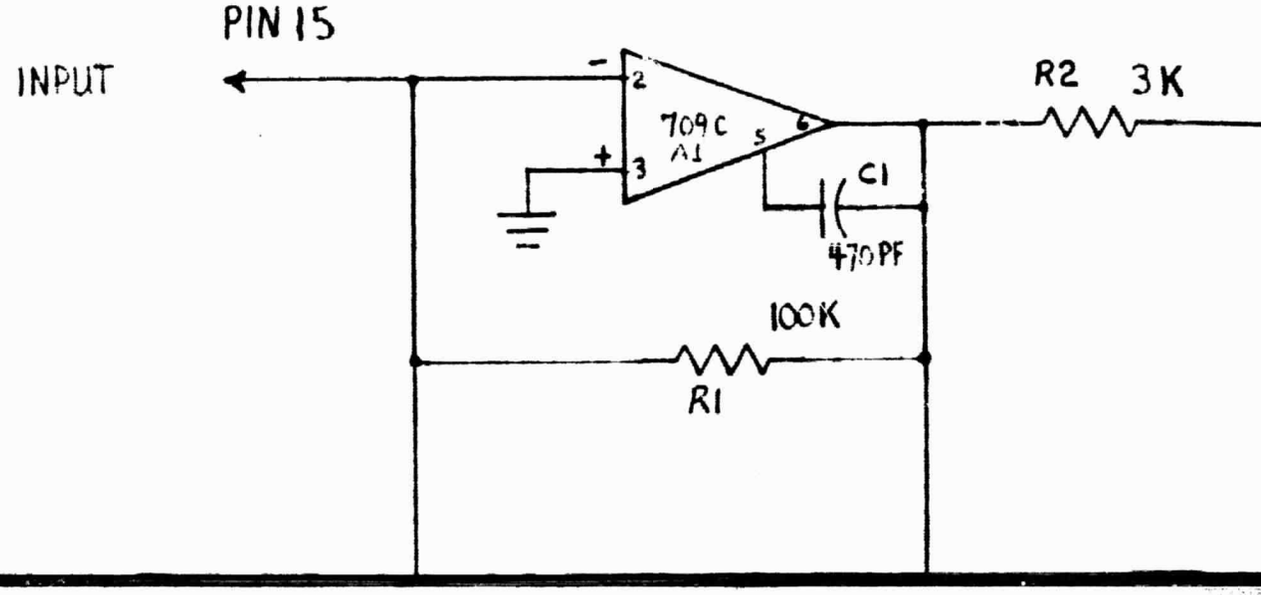


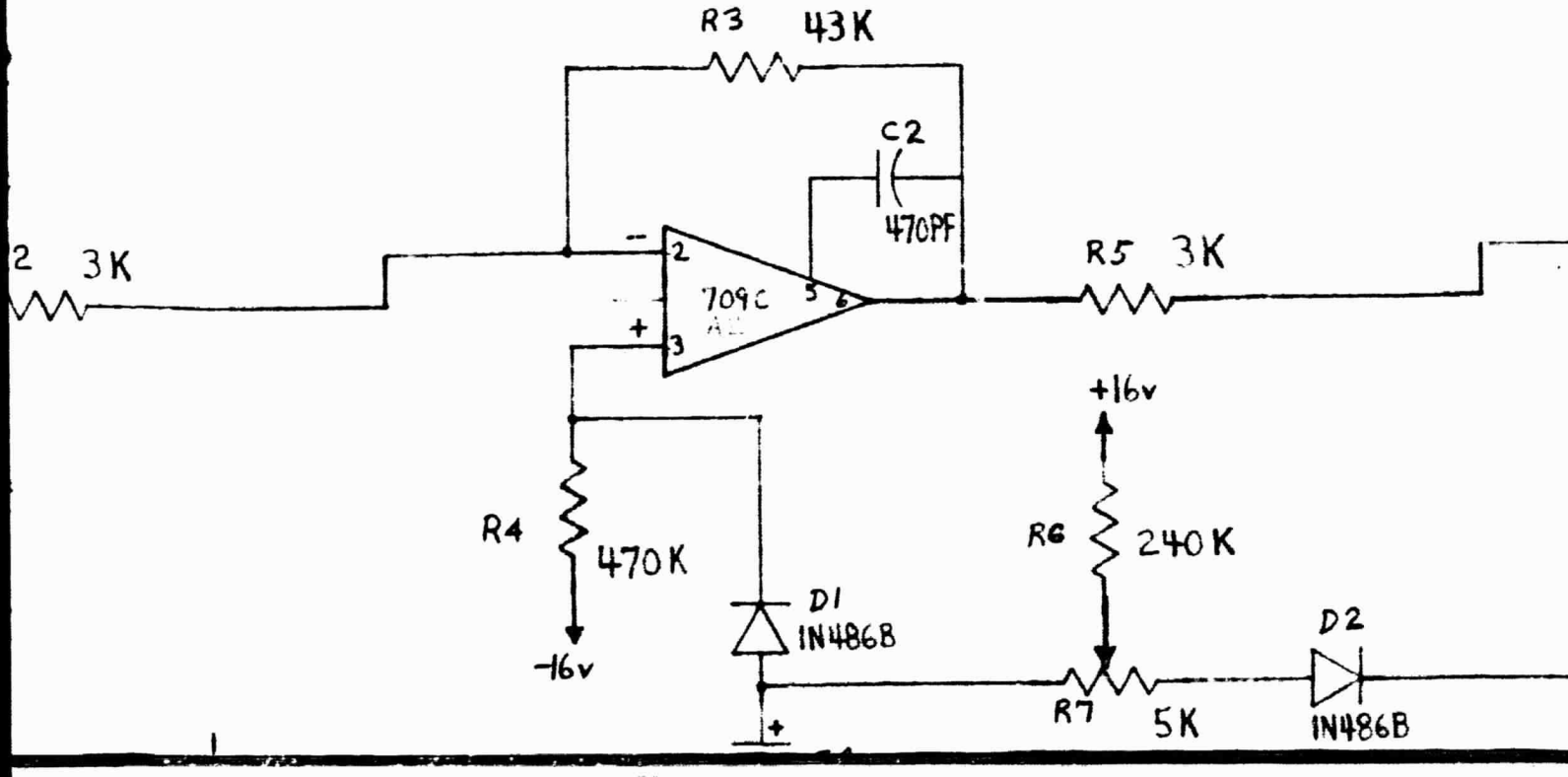
SCALE	
DWG. NO.	01114
DRAWN BY	
DATE	4-15-1968
PROJECTION ASSEMBLY	
MATERIAL	
HEAT TREAT CAL. ACT.	

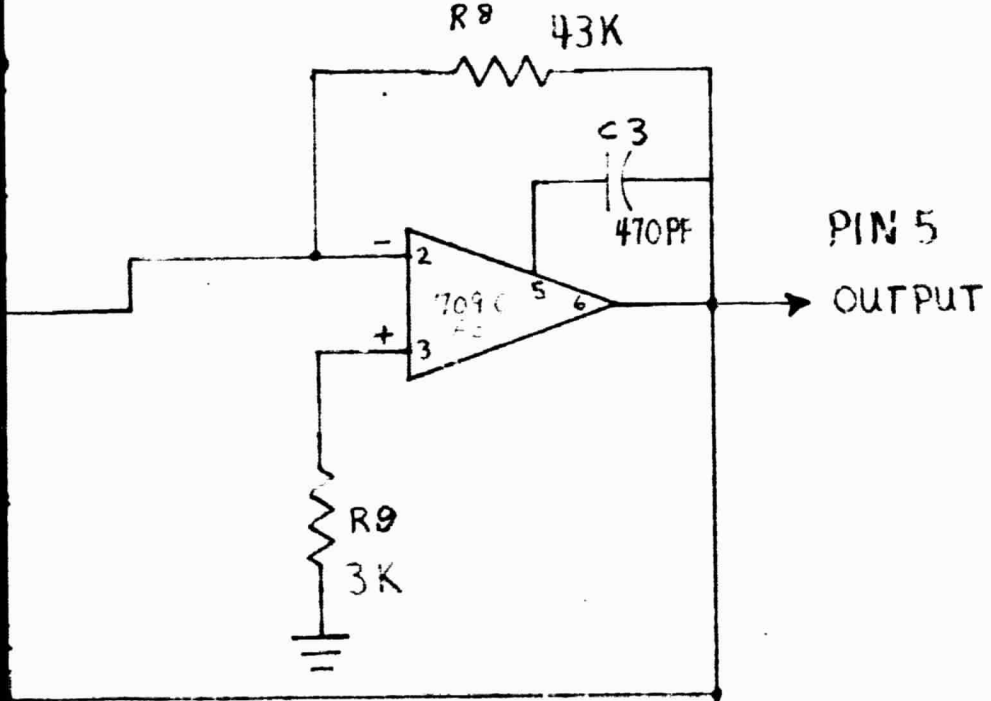
HIGH ALTITUDE ENGINEERING LABORATORY
UNIVERSITY OF MICHIGAN
DEPARTMENT OF AEROSPACE ENGINEERING
ANN ARBOR MICHIGAN

NAME PRE-AMPLIFIER, SIG. DISSECTOR

DRAWING NO. H3-52022


PIN 15
INPUT
709C
A1
2
3
6
5
R2 3K
C1
470 PF
100K
R1


R3 43K
C2
470PF
2 3K
709C
R5 3K
+16v
R4
470K
R6
240K
D1
IN4868
D2
-16v
R7
5K
IN486B

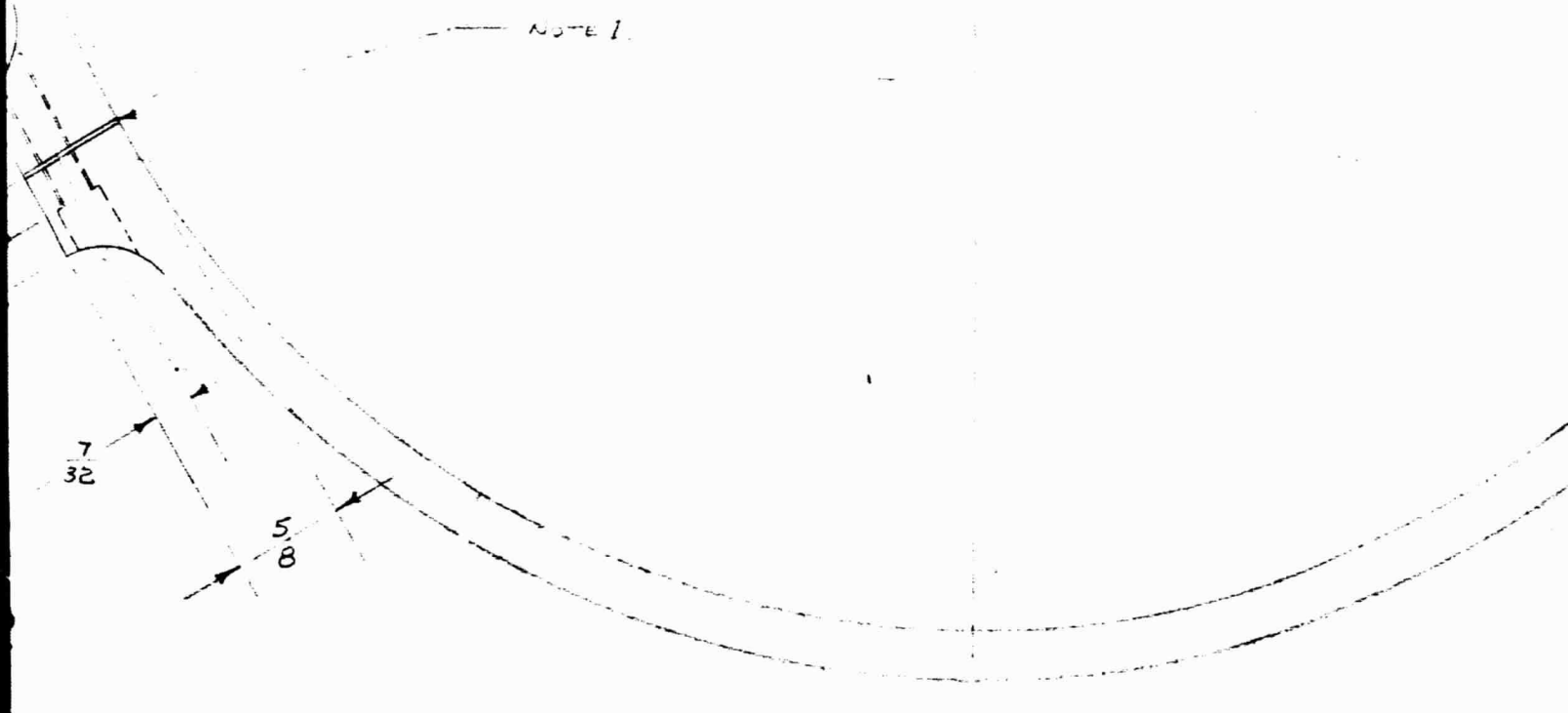

R8
43K
C3
470PF
PIN 5
OUTPUT
2
3
5
6
R9
3K

NOTES:

1. SLIT WITH 1/32 SAW
   OTHER MACHININ
2. DRILL THRU (3) PLAC
   LIMITS .174 - .180
   COIL PART NO. 2
   NOT TAP THRU.) C

30°

NOTE 1



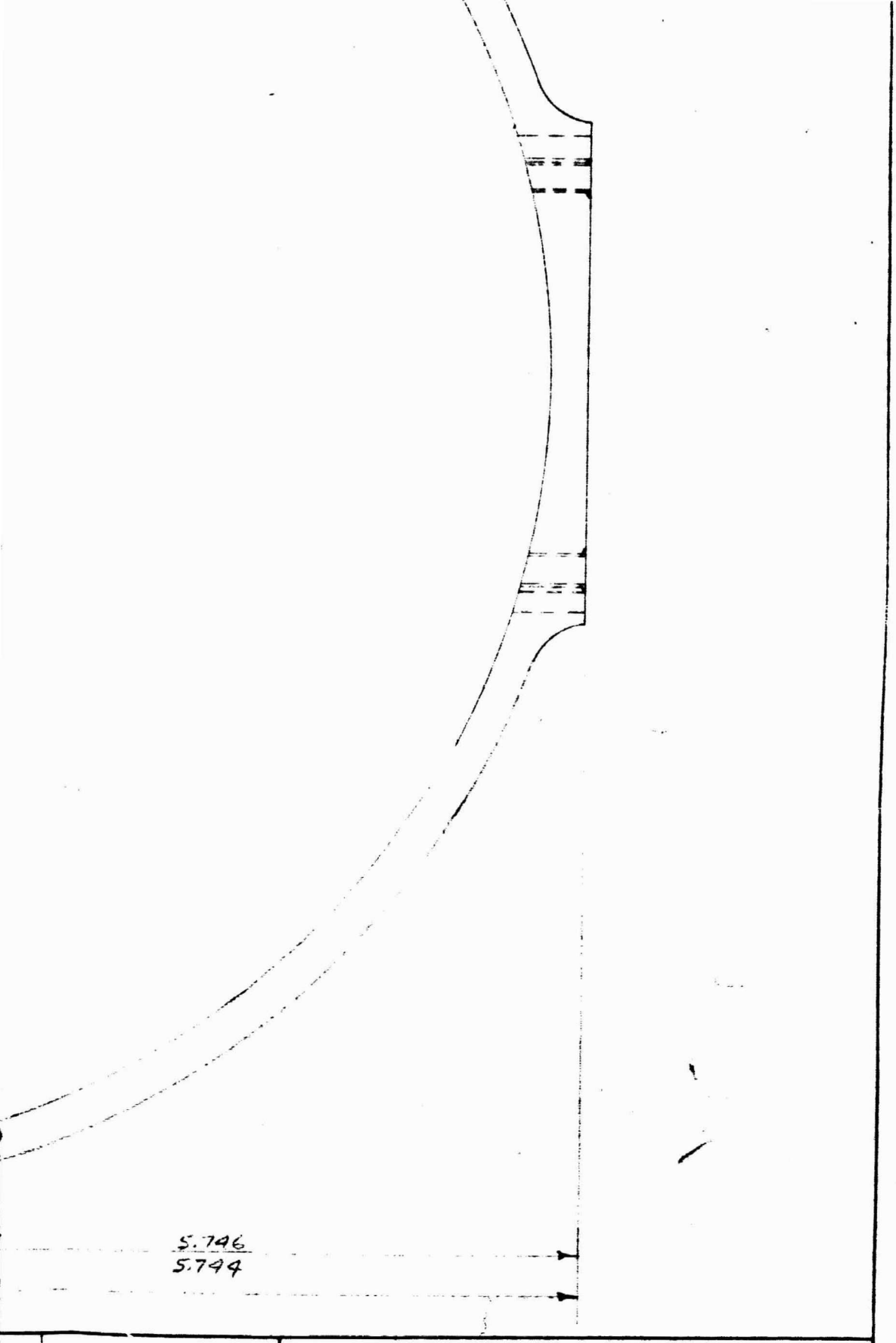
5.746
5.744

11.491
11.484

5.746
5.744

/32 SAW AFTER COMPLETION
CHINING & INSPECTION.
3) PLACES #16 DRILL. DIA.
-.180. TAP WITH HELI-
NO. 2CPA-H3. (TAP WILL
RU.) C'BORE .270 DIAM.

			SCALE	FULL
			PROJ. NO.	01114
			DRAWN BY	F 3
			DATE	4/20/68
			FOR ASSEMBLY	
			MATERIAL	AZ-31B
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	



	FULL
NO.	01114
N	F3
	4/20/68
LY	
AL	AZ-31B
CAL. ACT.	

HIGH ALTITUDE ENGINEERING LABORATORY
UNIVERSITY OF MICHIGAN
DEPARTMENT OF AERO. AND ASTRO. ENGINEERING
ANN ARBOR MICHIGAN

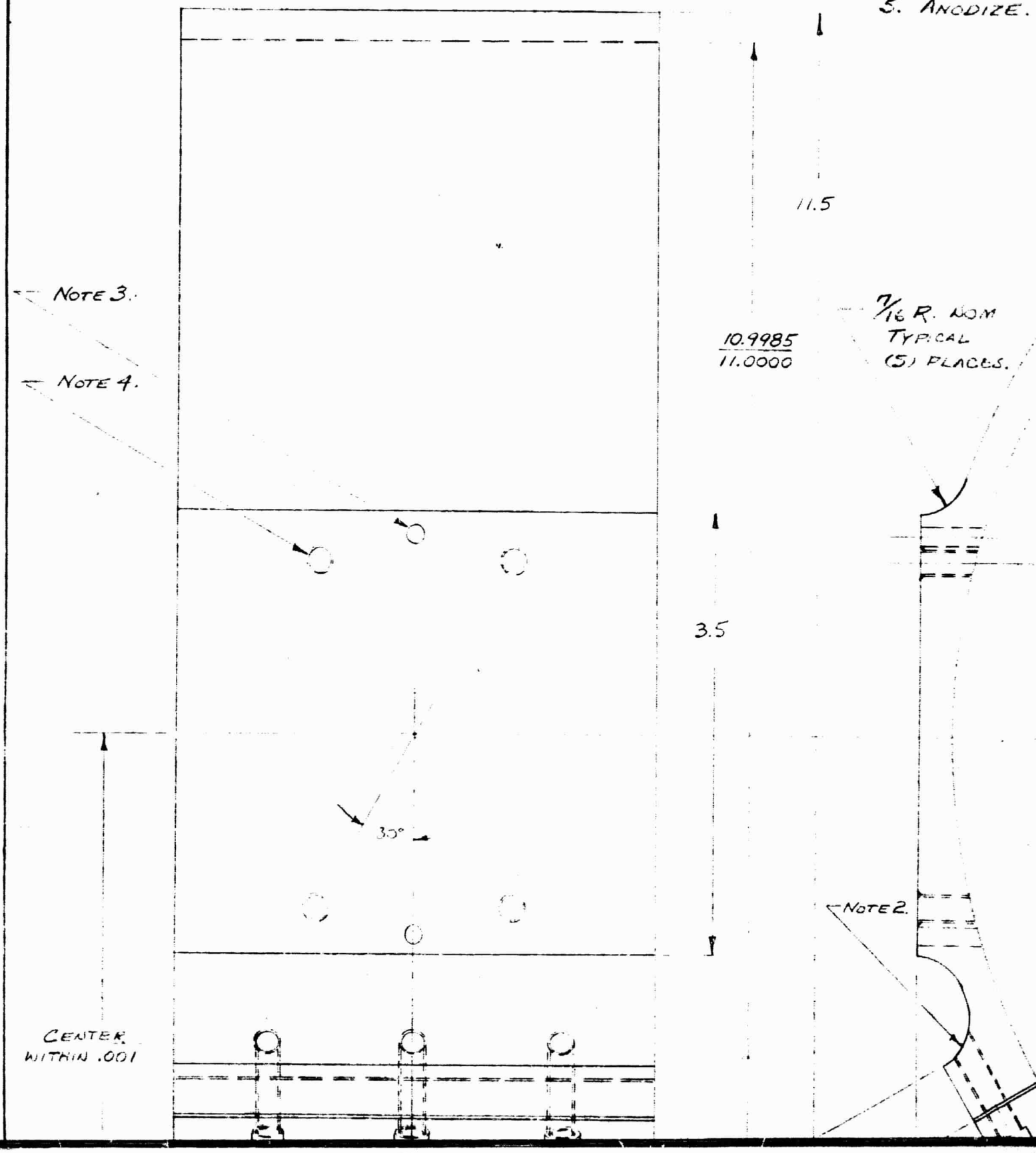
NAME INNER GIMBAL

DRAWING NO. H3-52023

III

NOTES:

3. DRILL TH
   ON CIRCL
4. DRILL TH
   TAP WITH
   DIAM. .20
5. ANODIZE.

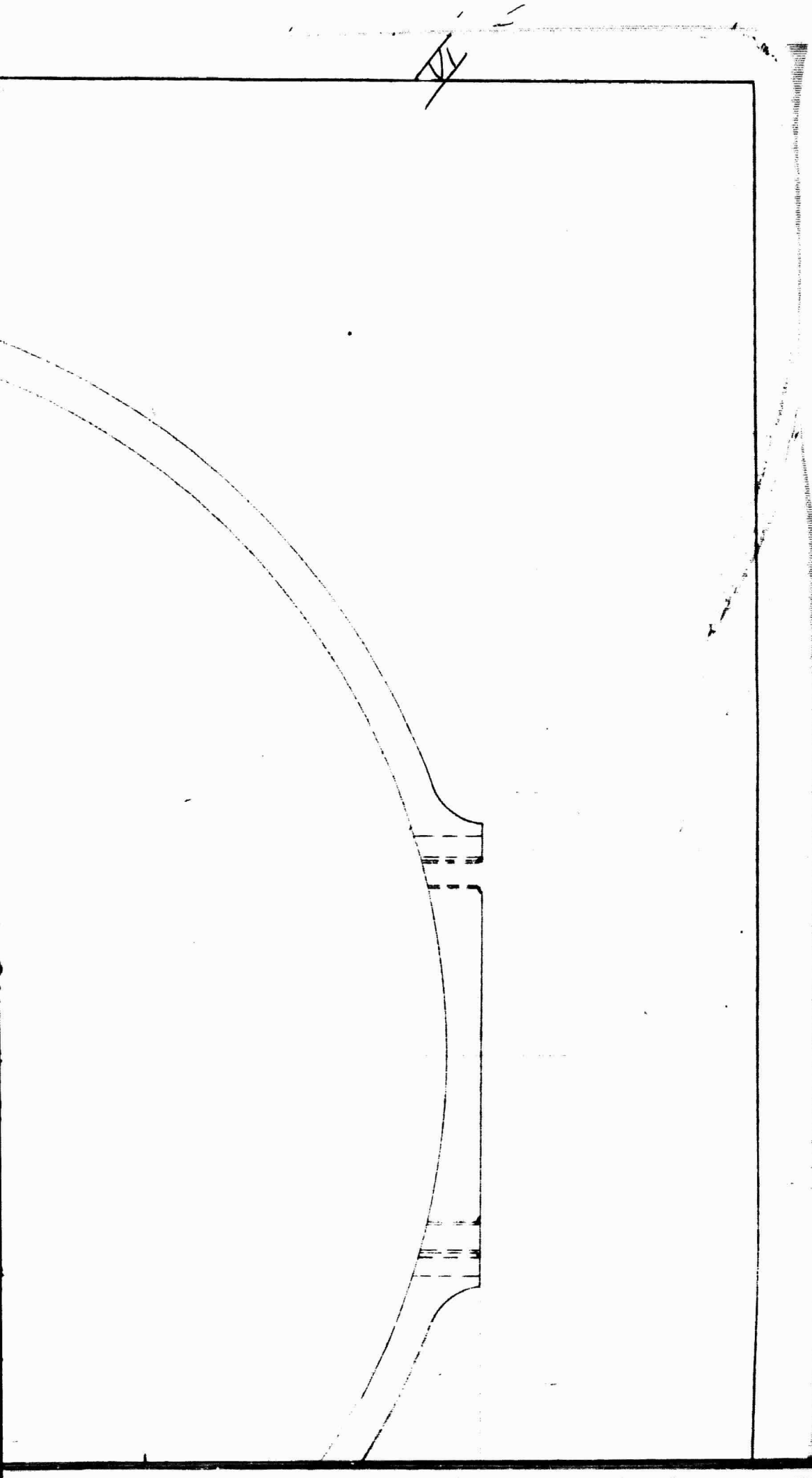


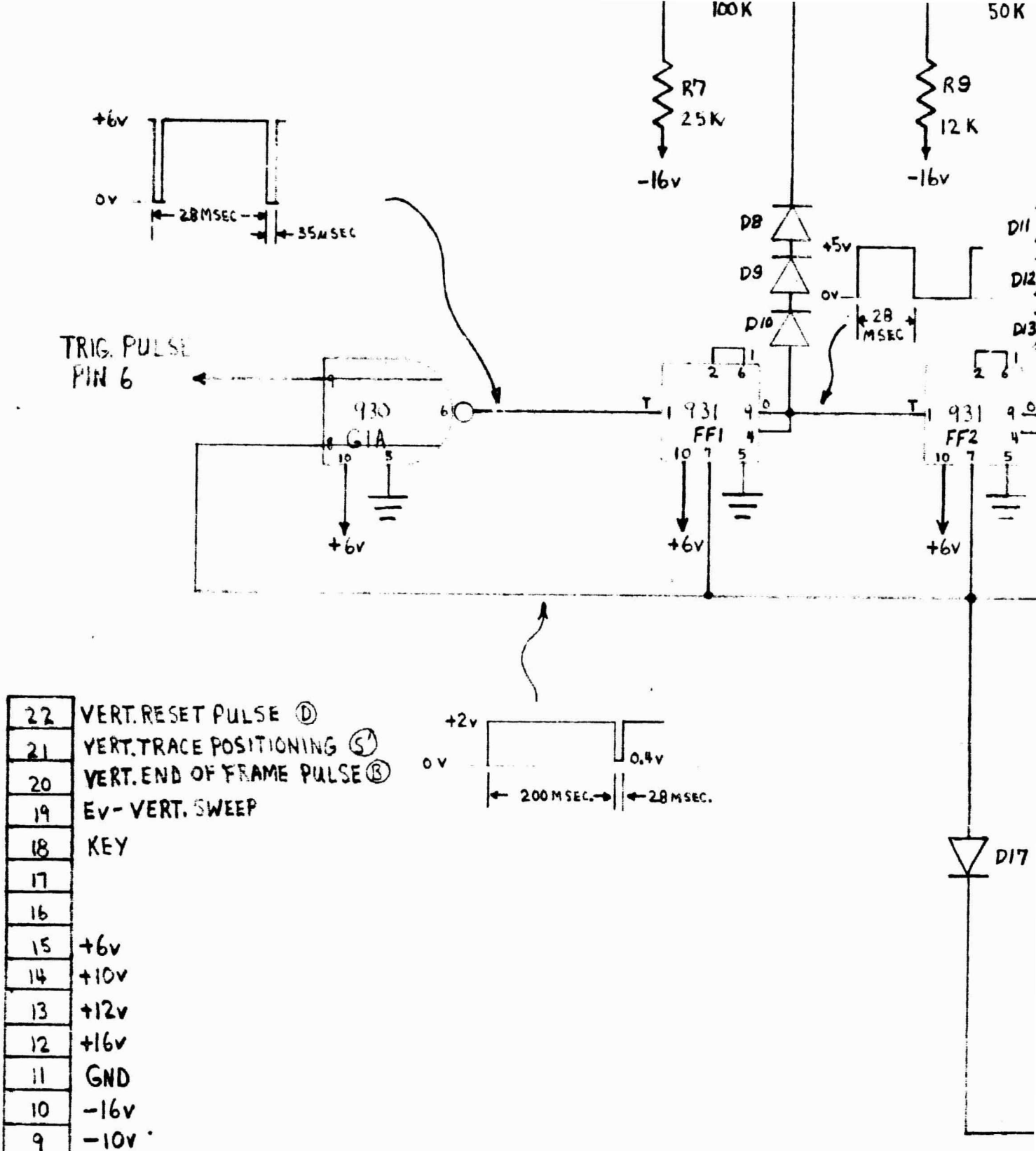
KILL THRU (2) HOLES .1354 ±.0002 DIA. ON 3.1570 ±.0002 B.C.
ON CIRCLE CONCENTRIC WITH NOTE 4 HOLES. TYPICAL (2) PLACES.
RILL THRU (4) HOLES #16 DRILL DIA. LIMITS .174-.180. 3.157 ±.001 B.C.
F WITH HELI-COIL PART #2 CPA-H3 AFTER C'SINK 120° TO
AM. .20-.23. TYPICAL (2) PLACES.
NODIZE. .0001-.0003 THICK.

M.M
AL
PLACES.

30°

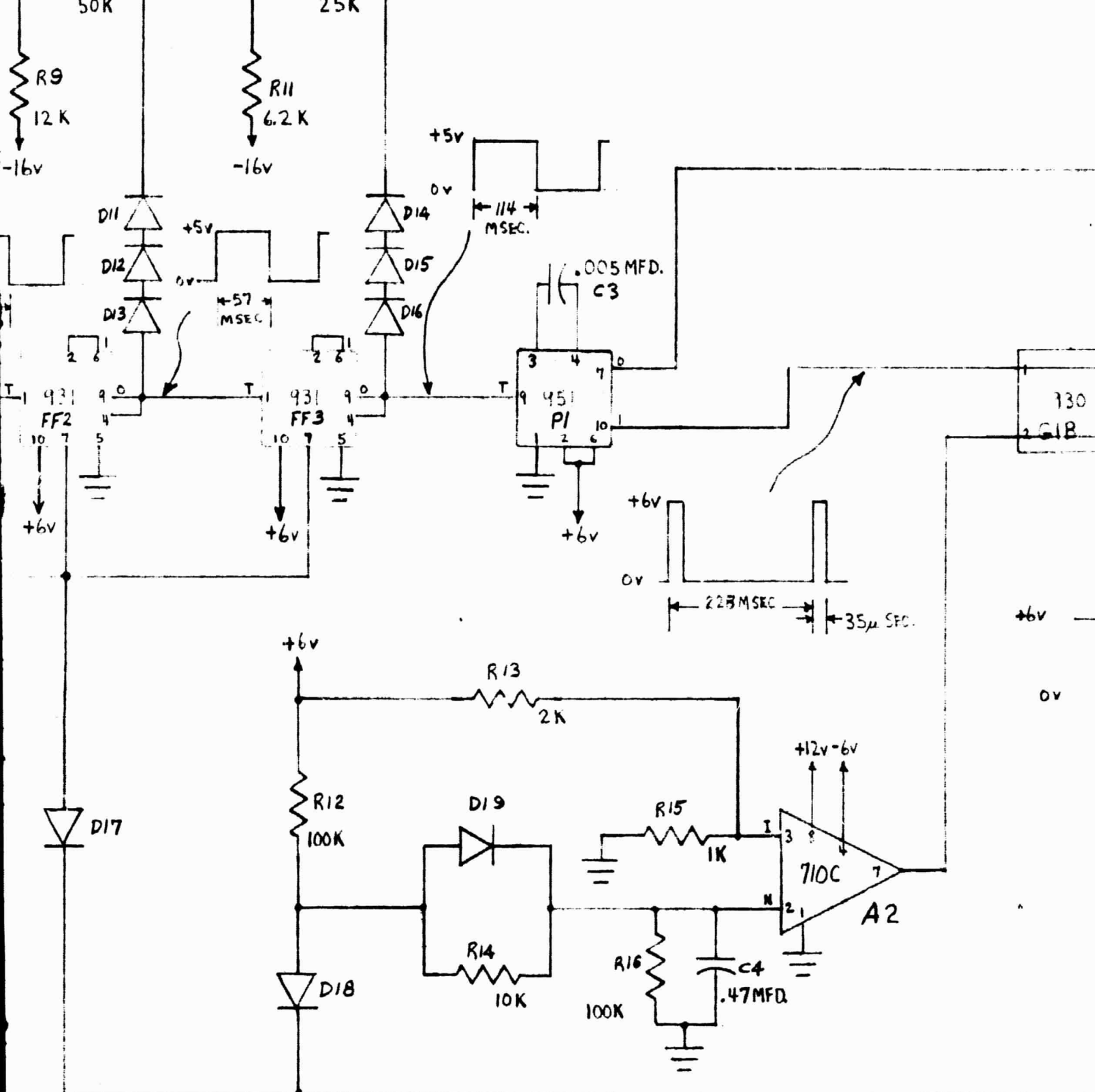
NOTE 1.





22	VERT. RESET PULSE Ⓓ
21	VERT. TRACE POSITIONING Ⓢ'
20	VERT. END OF FRAME PULSE Ⓡ
19	Ev - VERT. SWEEP
18	KEY
17	
16	
15	+6v
14	+10v
13	+12v
12	+16v
11	GND
10	-16v
9	-10v
8	-6v
7	
6	TRIG. PULSE
5	
4	
3	
2	
1	

NOTE
1. ALL DIODES ARE IN486B
2. ALL RESISTORS ARE ¼w 5%
3. TO RESET VERT. TRACE TO BOTTOM OF RASTE
   BOTH OF THE FOLLOWING CONDITIONS MUS
   3A S' GROUNDED
   3B S14 INHIBITED

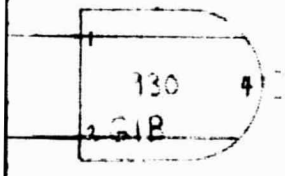


F RASTER (I.C.S.W.),
ONS MUST EXIST.

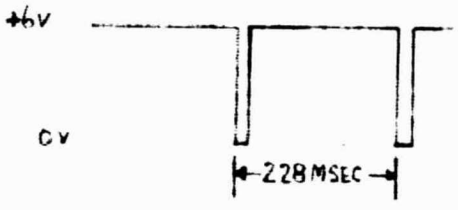
			SCALE	
			PROJ. NO.	01114
			DRAWN BY	ED GILREA
			DATE	4-29-68
			FOR ASSEMBLY	
			MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

(½ WAVELENGTH)

VERT. RESET PULSE
PIN 22 (D)
SAME AS END OF FRAME PULSE, EXCEPT ALL PULSES ARE SEEN.

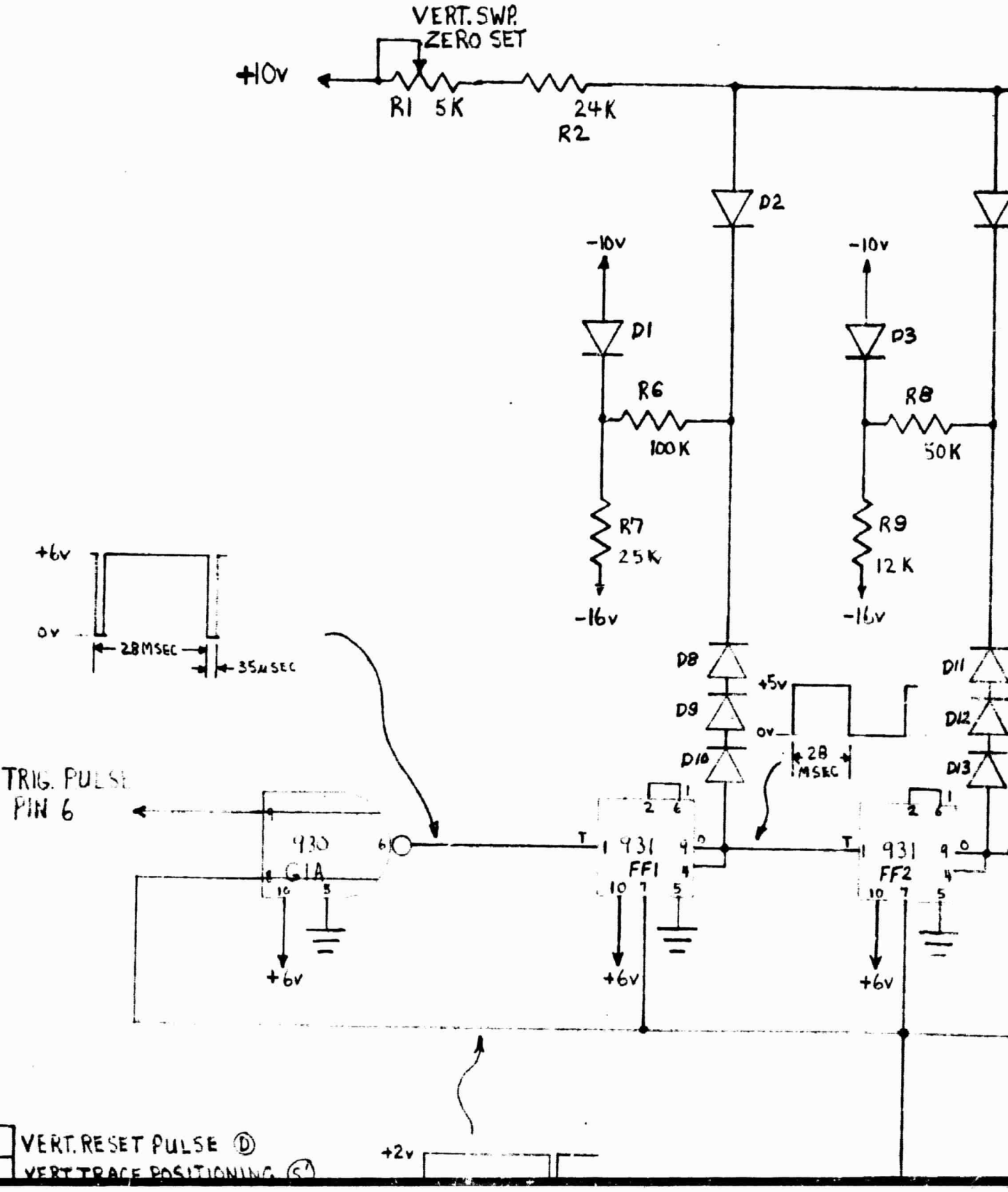


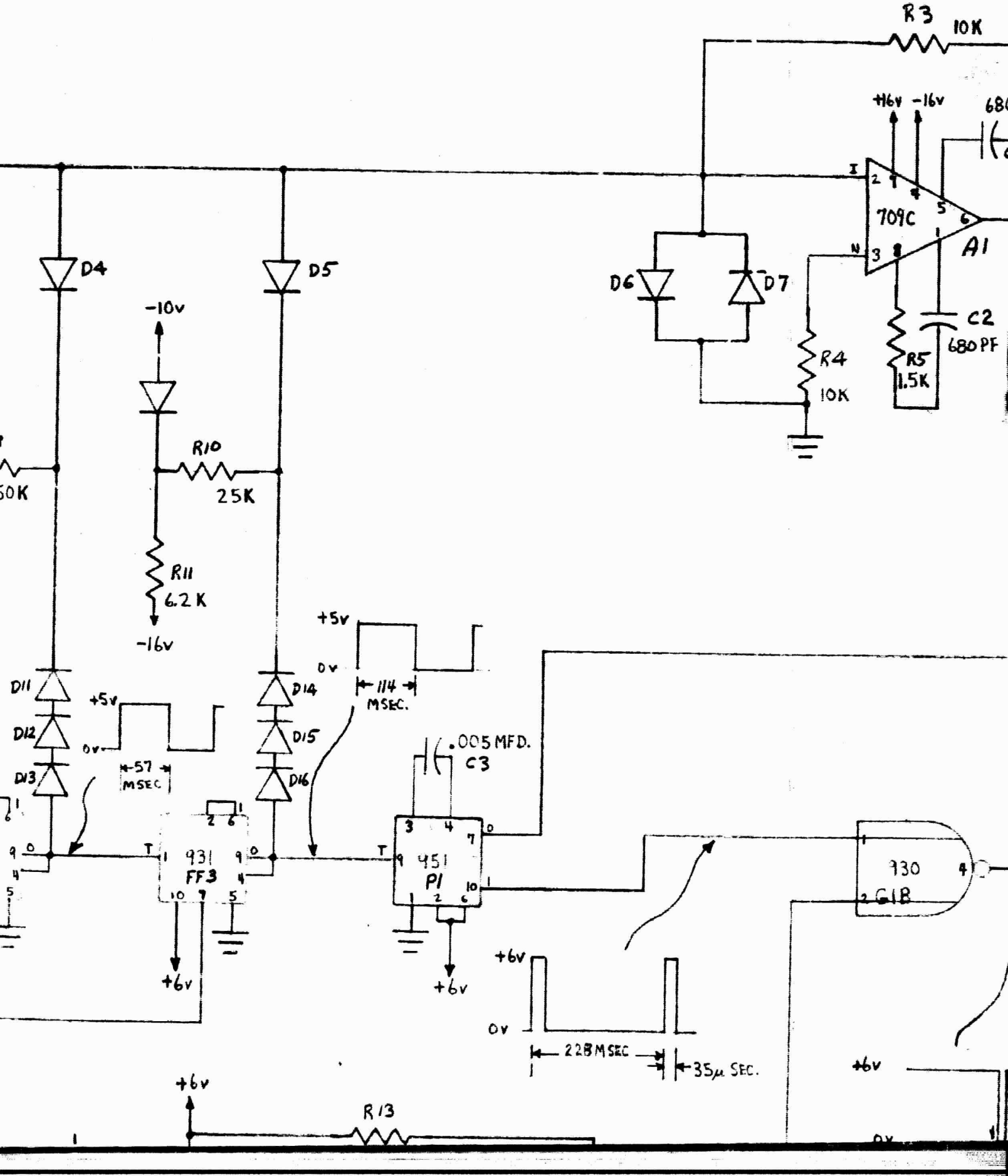
VERT. END OF FRAME PULSE - PIN 20 (E)
NO INITIAL PULSE WHEN CIRCUITS RESET TO I.C. AND THEN INITIATED.

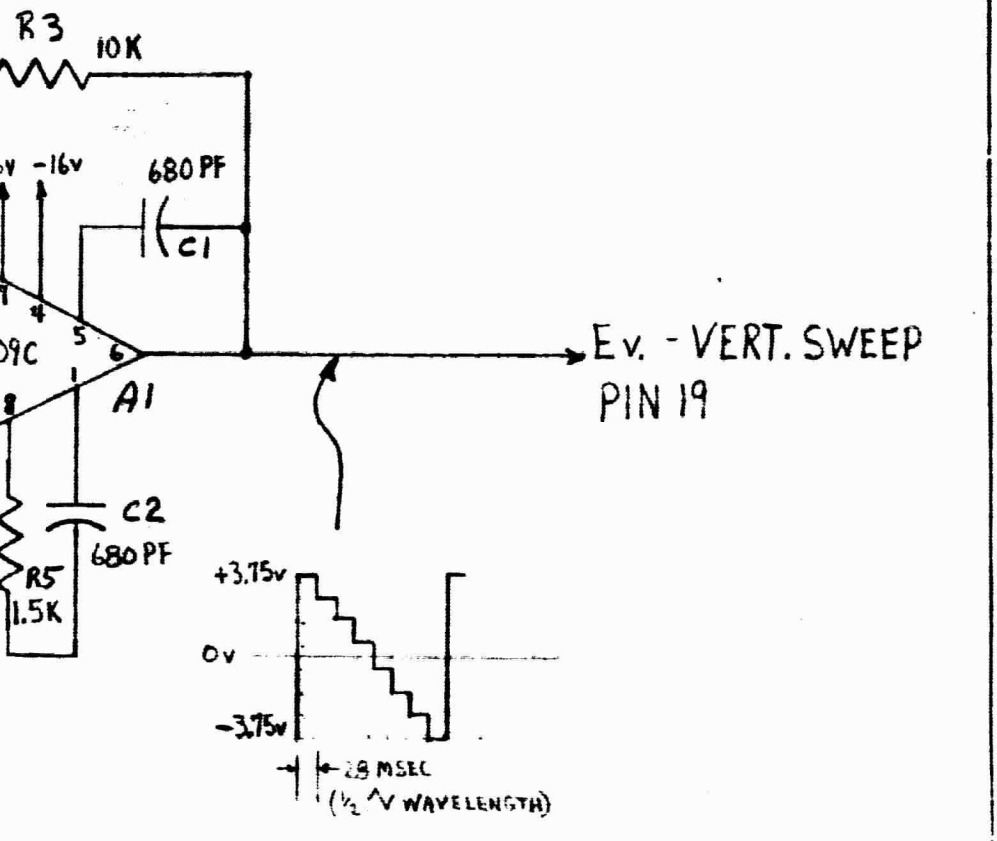


(S') VERT. TRACE POSITIONING PIN 21 .
OPEN TO OPER., GND TO ACT.

	HIGH ALTITUDE ENGINEERING LABORATORY **UNIVERSITY OF MICHIGAN** ***DEPARTMENT OF AEROSPACE ENGINEERING*** **ANN ARBOR MICHIGAN**
S114	
ED GILREATH	
4-29-68	**NAME** VERT. RASTER SCAN GENERATOR J7
	DRAWING NO. H3-52025


VERT. SWP.
ZERO SET
+10v
R1 5K
24K
R2
D2
-10v
D1
R6
100K
R7
25K
-16v
-10v
D3
R8
50K
R9
12K
-16v
+6v
0v
28 MSEC
35 MSEC
D8
D9
D10
+5v
0v
28 MSEC
D11
D12
D13
TRIG. PULSE
PIN 6
930
G1A
931
FF1
931
FF2
+6v
+6v
+6v
22 VERT. RESET PULSE Ⓓ
+2v
VERT TRACE POSITIONING Ⓢ

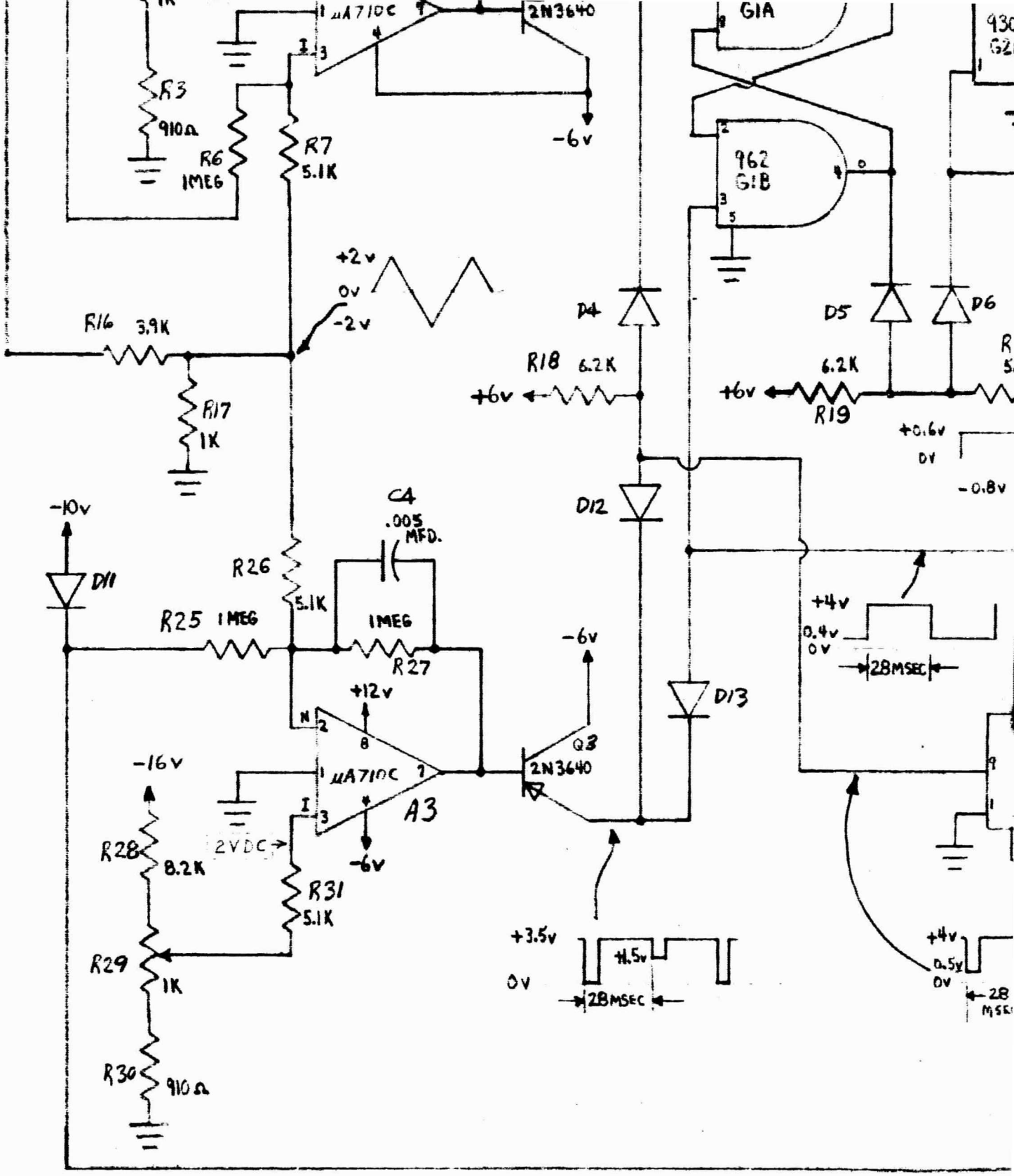

R3
10K
+16v
-16v
709C
A1
D4
D5
D6
D7
R4
10K
R5
1.5K
C2
680 PF
-10v
R10
25K
R11
6.2K
-16v
+5v
0v
114 MSEC.
D11
D12
D13
D14
D15
D16
57 MSEC
.005 MFD.
C3
931
FF3
951
P1
930
G1B
+6v
0v
228 MSEC
35μ SEC.
R13



Ev. - VERT. SWEEP
PIN 19

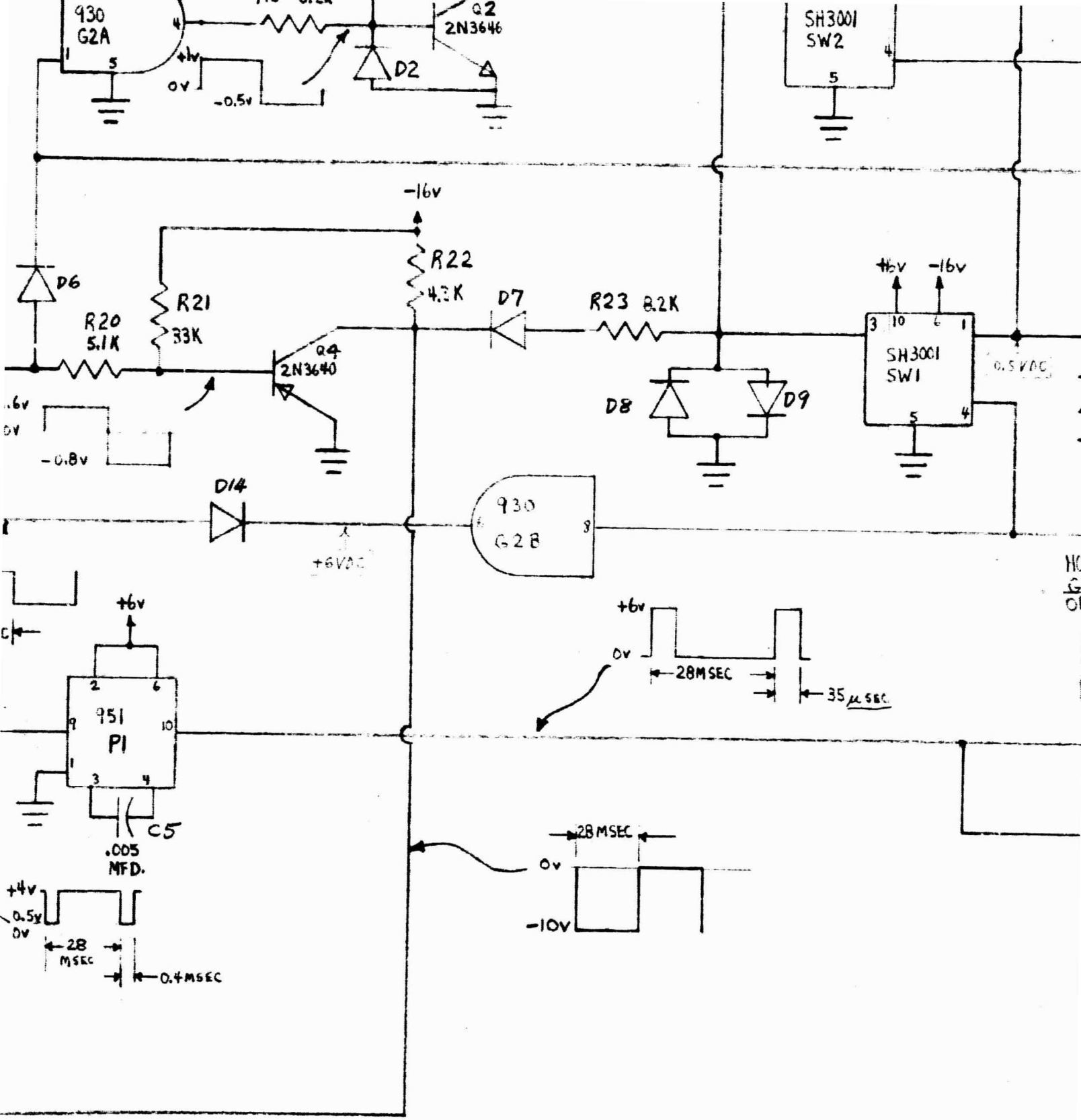
VERT. RESET PULSE
PIN 22 (D)
SAME AS END OF FRAME PULSE, EXCEPT ALL PULSES ARE SEEN.

VERT. END OF FRAME
PULSE - PIN 20 (B)
NO INITIAL PULSE WHEN CIRCUITS RESET TO I.C. AND THEN INITIATED.



NOTE:

1. ALL DIODES IN486B UNLESS NOTED.
2. ALL RESISTORS ¼w 5% UNLESS NOTED
3. S8 IS IC (INITIAL CONDITION) SW TO RETURN HORIZ. SWP. TO RIG
   GROUND TO OPER., OPEN TO INHIBIT
4. CLOSING S AND INHIBITING $\overline{S14}$ ALLOWS HORIZ. TRACE TO D
   REQUIRES +6v TO ACTIVATE WHEN S8 IS INHIBITED.

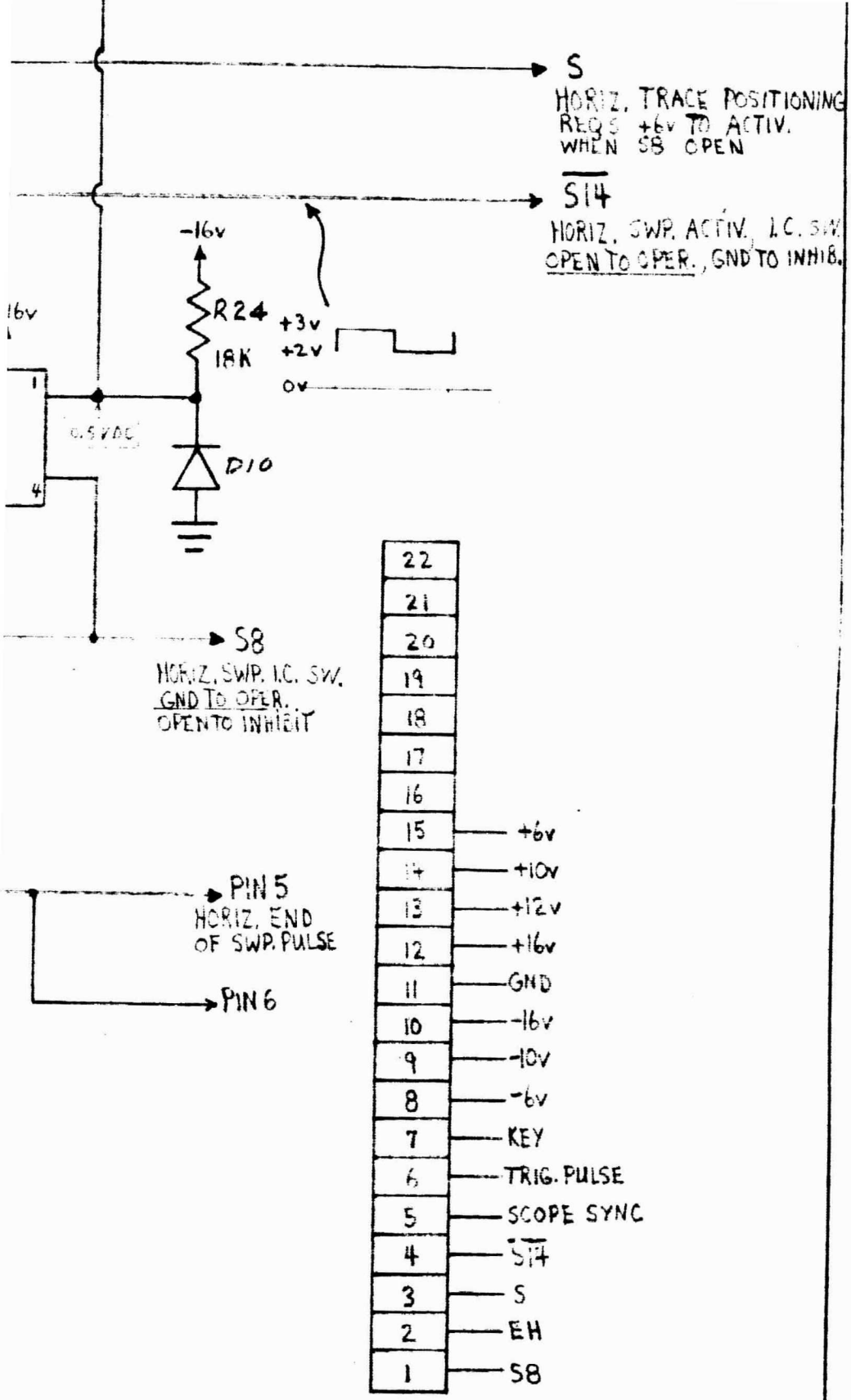


P, TO RIGHT.

E TO DRIFT TO CEN. OF RASTER.

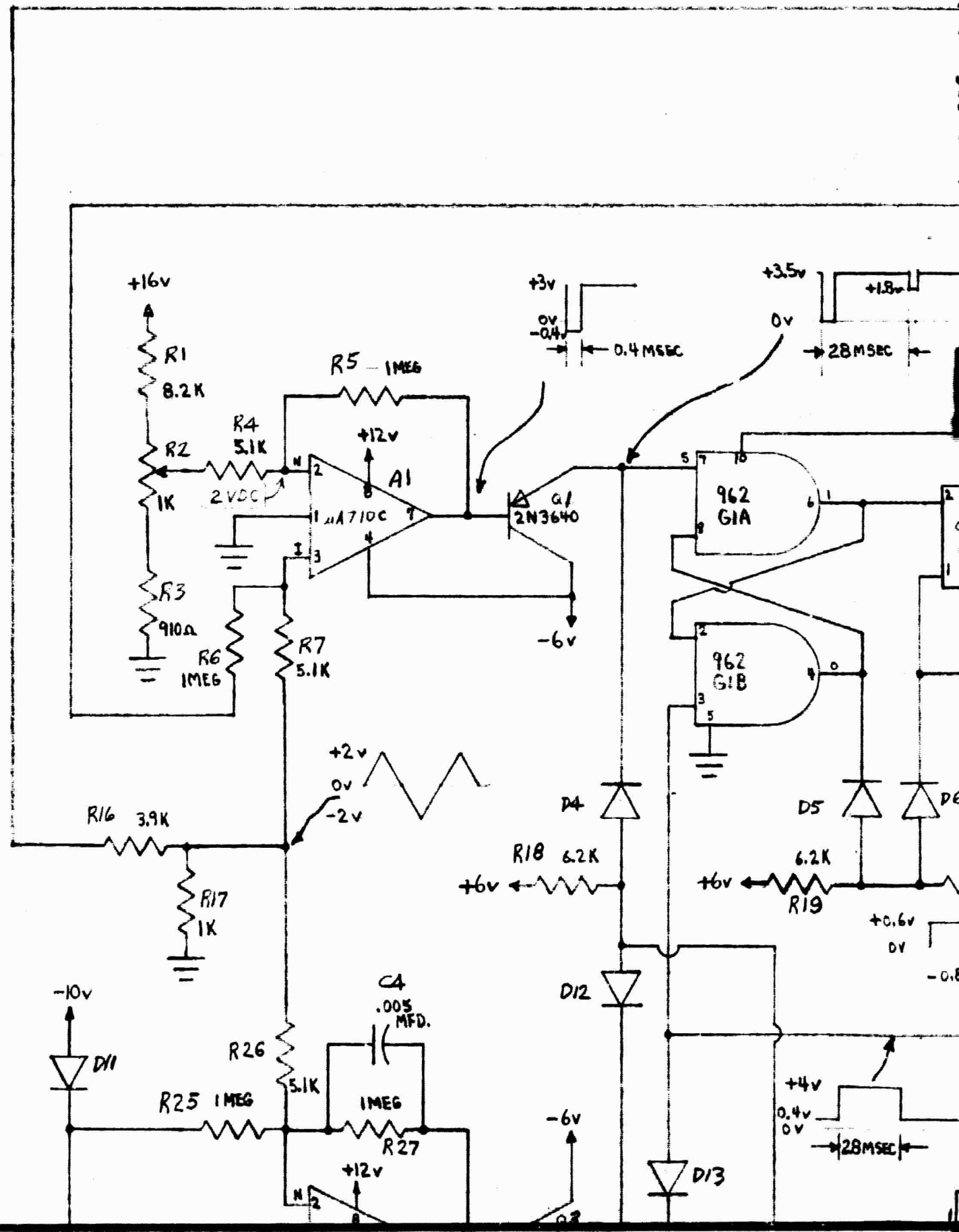
ITED.

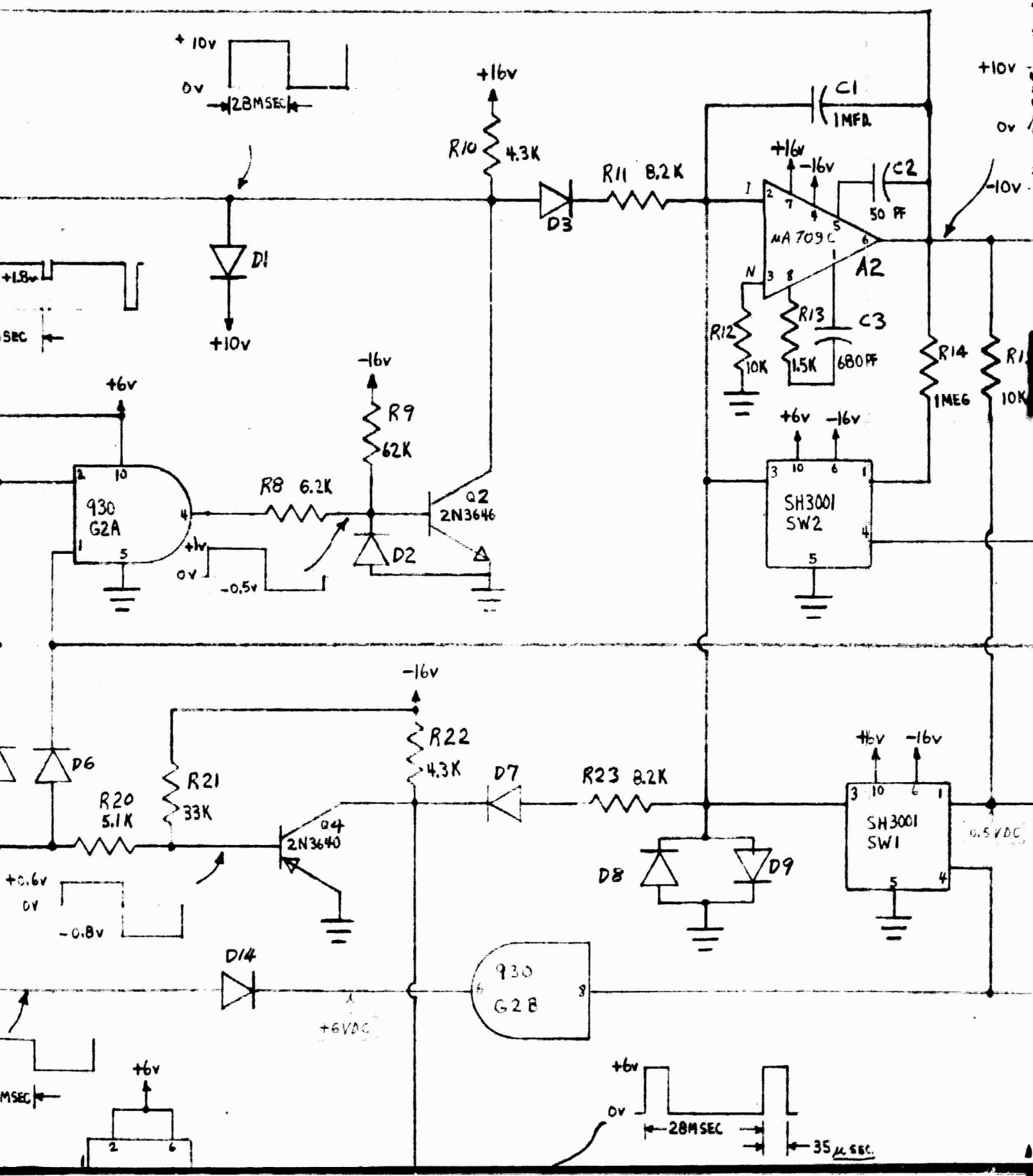
			SCALE	
			PROJ. NO.	01114
			DRAWN BY	
			DATE	5-9-68
			FOR ASSEMBLY	
			MATERIAL	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.	

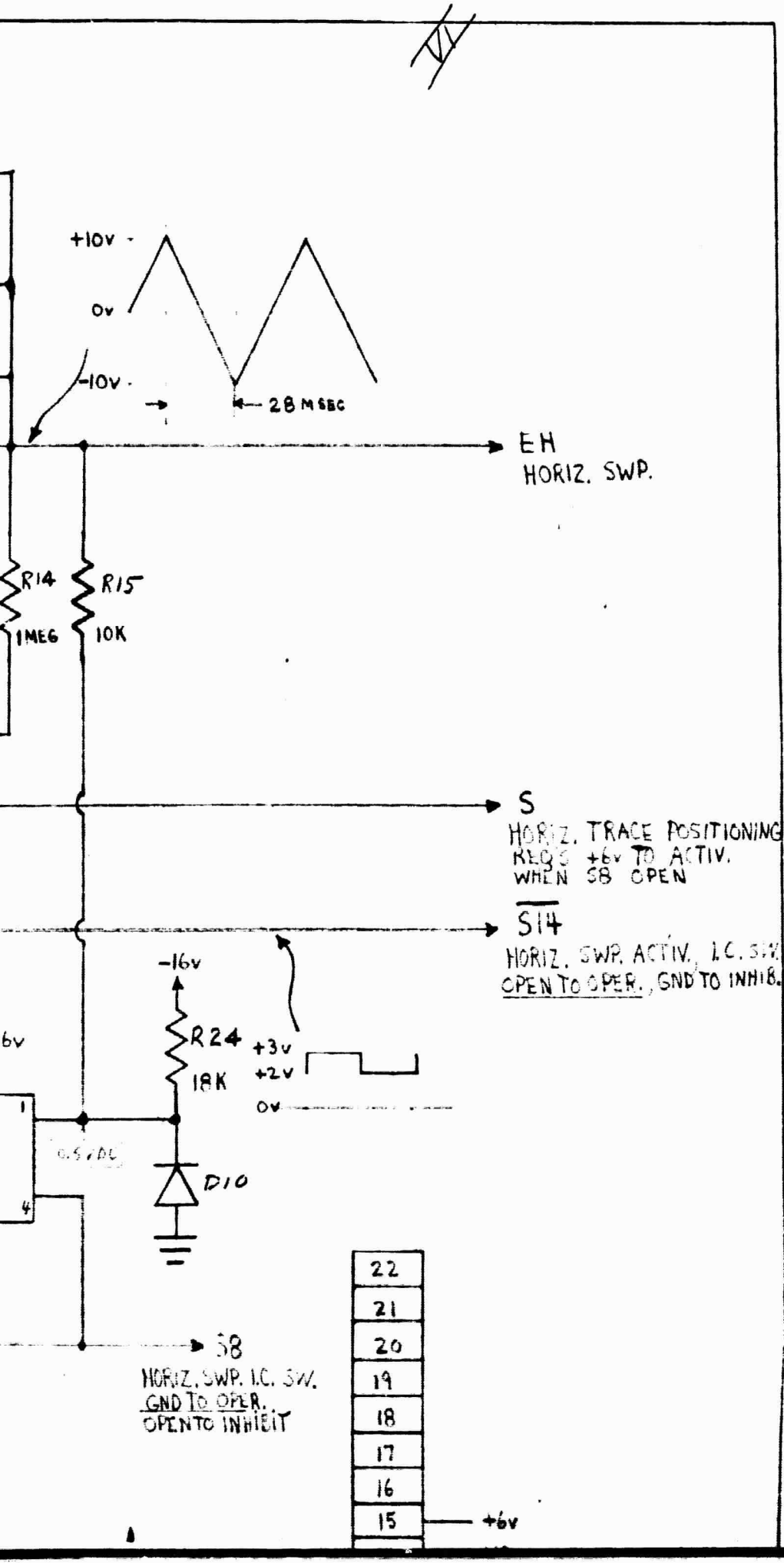


	HIGH ALTITUDE ENGINEERING LABORATORY **UNIVERSITY OF MICHIGAN** ***DEPARTMENT OF AEROSPACE ENGINEERING*** **ANN ARBOR MICHIGAN**
	NAME HORIZ. RASTER SCAN GENERATOR
	DRAWING NO. H3-52026

1

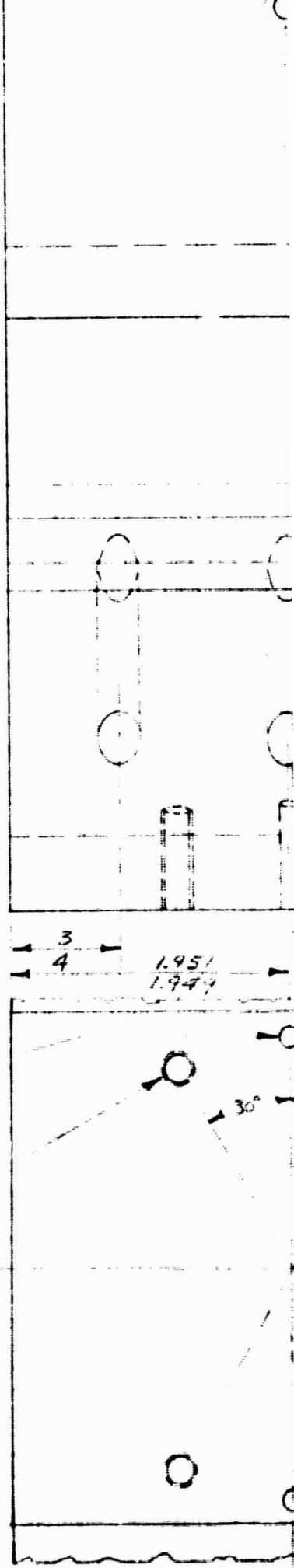

+16v
R1
8.2K
R2
1K
R3
910Ω
R4
5.1K
R5 1MEG
R6
1MEG
R7
5.1K
+12v
A1
2VDC
1 μA710C
Q1
2N3640
-6v
+3v
0v
-0.4v
0.4 MSEC
+3.5v
+1.8v
0v
28MSEC
962
G1A
962
G1B
+2v
0v
-2v
R16 3.9K
R17
1K
D4
D5
R18 6.2K
+6v
6.2K
R19
+6v
+0.6v
0v
D12
-10v
D11
C4
.005
MFD.
R26
5.1K
R25 1MEG
1MEG
R27
+12v
-6v
D13
+4v
0.4v
0v
28MSEC


+10v
0v
28MSEC
+16v
R10
4.3K
R11 8.2K
C1
1MFD
D3
D1
+10v
+1.8v
SEC
+16v
-16v
C2
50 PF
-10v
μA 709C
A2
R12
10K
R13
1.5K
C3
680PF
R14
1MEG
R1
10K
+6v
-16v
SH3001
SW2
+6v
930
G2A
R8 6.2K
R9
62K
-16v
Q2
2N3646
D2
+1v
0v
-0.5v
-16v
R22
4.3K
D7
R23 8.2K
D6
R21
33K
R20
5.1K
Q4
2N3640
+0.6v
0v
-0.8v
+16v
-16v
SH3001
SW1
0.5VDC
D8
D9
D14
930
G2B
+6VDC
+6v
MSEC
+6v
0v
28MSEC
35μSEC


+10v
0v
-10v
28 M SEC
EH
HORIZ. SWP.
R14
1MEG
R15
10K
S
HORIZ. TRACE POSITIONING
REQ'S +6v TO ACTIV.
WHEN S8 OPEN
S14
HORIZ. SWP. ACTIV. I.C. S.W.
OPEN TO OPER., GND TO INHIB.
-16v
R24
18K
+3v
+2v
0v
D10
S8
HORIZ. SWP. I.C. S.W.
GND TO OPER.
OPEN TO INHIBIT
22
21
20
19
18
17
16
15
+6v

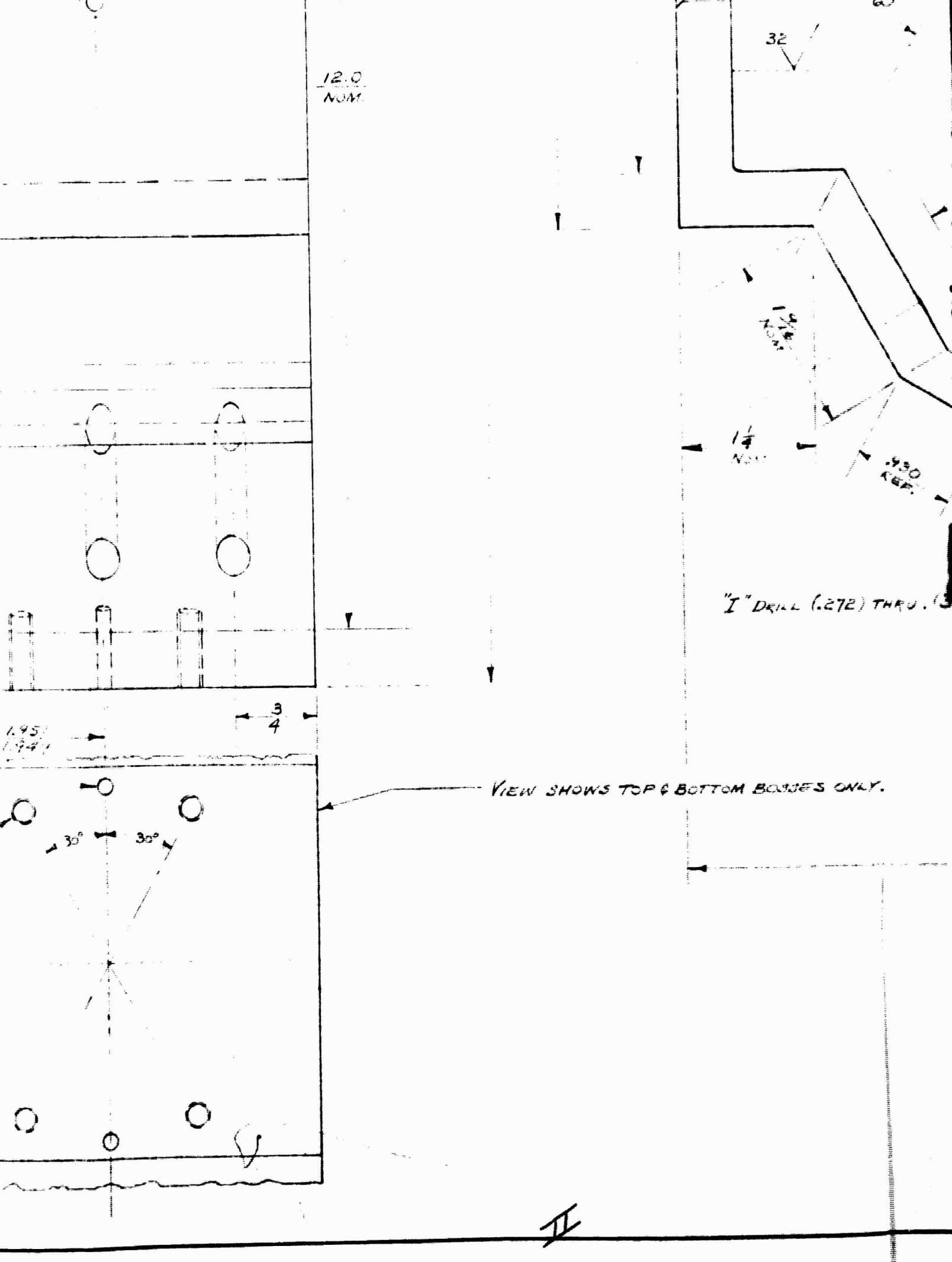
#28 DRILL.
DRILL THRU (4) HOLES EQUALLY SPACED
ON .750 ± .001 B.C. LOCATE CENTER TO .001.
82° C'SINK TO .280 DIA.
TYPICAL (2) PLACES

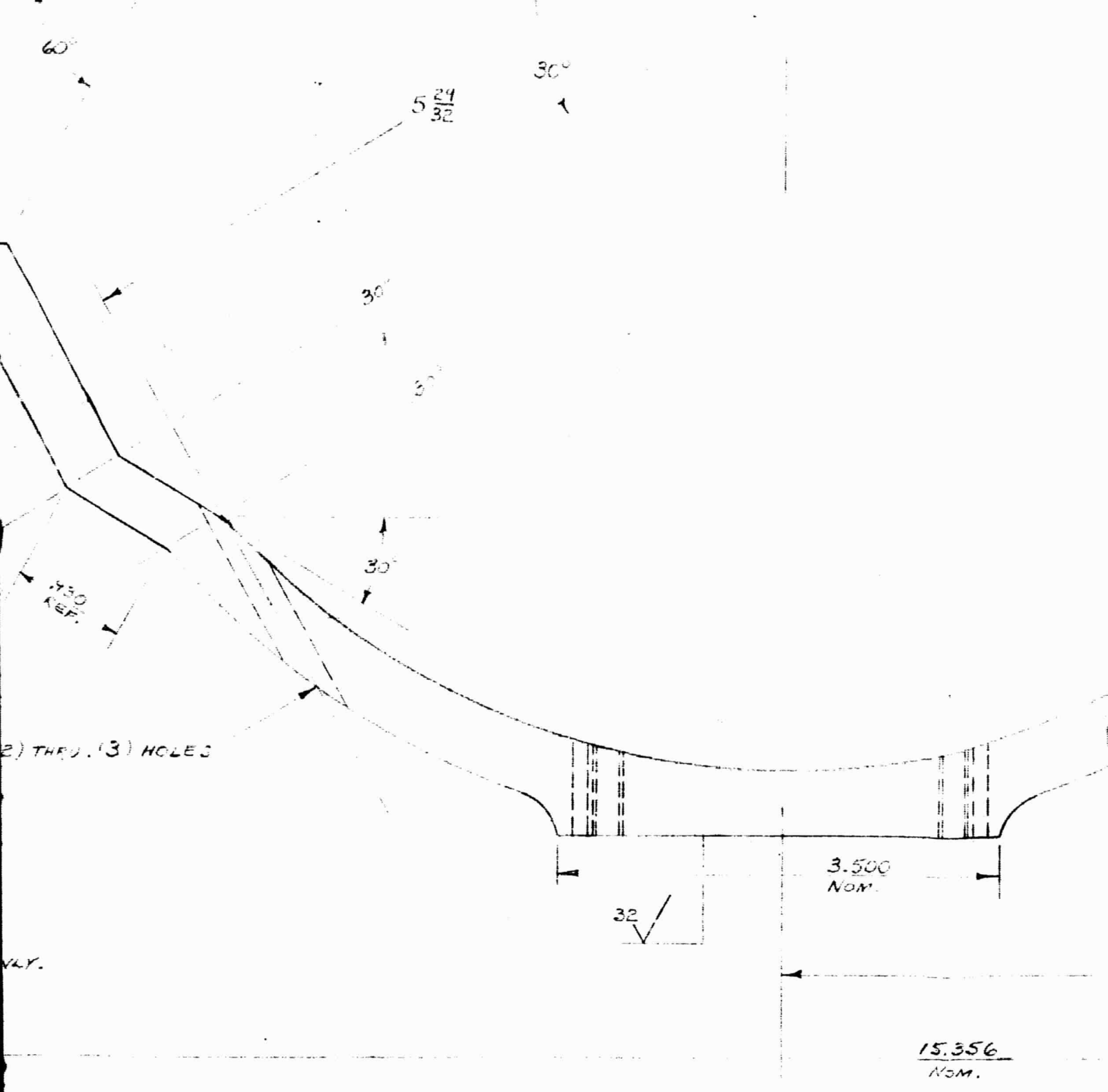
.3752 - .3754 DIAM. HOLE
C'BOR 1/16 NOM.
LOCATE CENTER TO .001
TYPICAL (2) PLACES



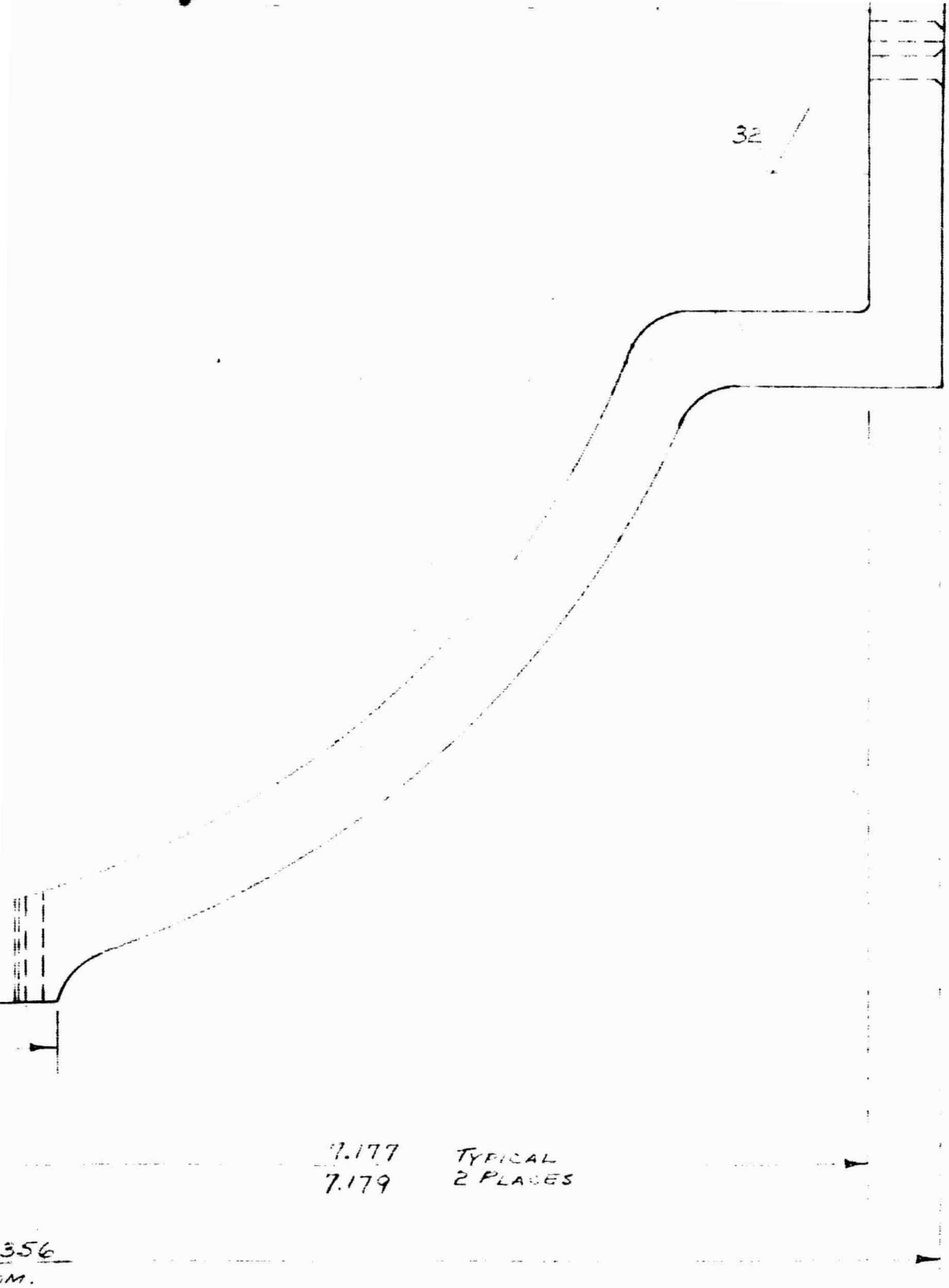
(2) HOLES. ON 3.1570 ± .0002 B.C.
.1252 - .1255 DIA. LOCATE CENTER TO .001.
CHAMFER 1/16 NOM.
TYPICAL (2) PLACES.

DRILL THRU (4) HOLES.
#16 DRILL. DIAM. LIMITS .174 - .180
3.157 ± .001 B.C. LOCATE CENTER TO .001.
C'SINK 120° TO .20 - .23 DIAM. TAP WITH HELI-COIL
PART No. 2-CPA-H3. TYPICAL (2) PLACES


12.0
NOM.
32
1 1/4
NOM.
"I" DRILL (.272) THRU.
3/4
1.95
(1.941)
30°
30°
VIEW SHOWS TOP & BOTTOM BOSSES ONLY.



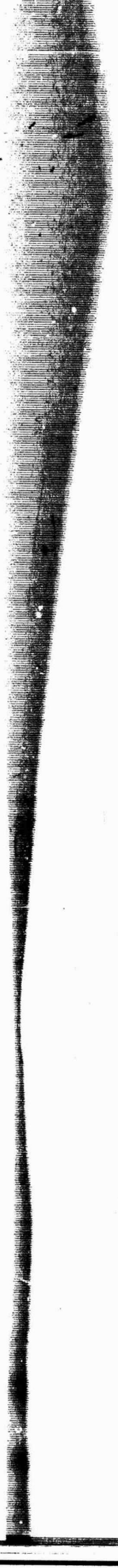
LET.



356
M.

			SCALE	FULL	HIGH ALTITUDE ENGINEERIN
			PROJ. NO.	01114	UNIVERSITY OF MICH
			DRAWN BY	F3	DEPARTMENT OF AERO. AND AST
			DATE	4-23-68	ANN ARBOR
			FOR ASSEMBLY		NAME MIDDLE G
			MATERIAL	AZ-31B	
LET.	CHANGE	DATE	WEIGHT CAL. ACT.		DRAWING NO. H5-52

IV



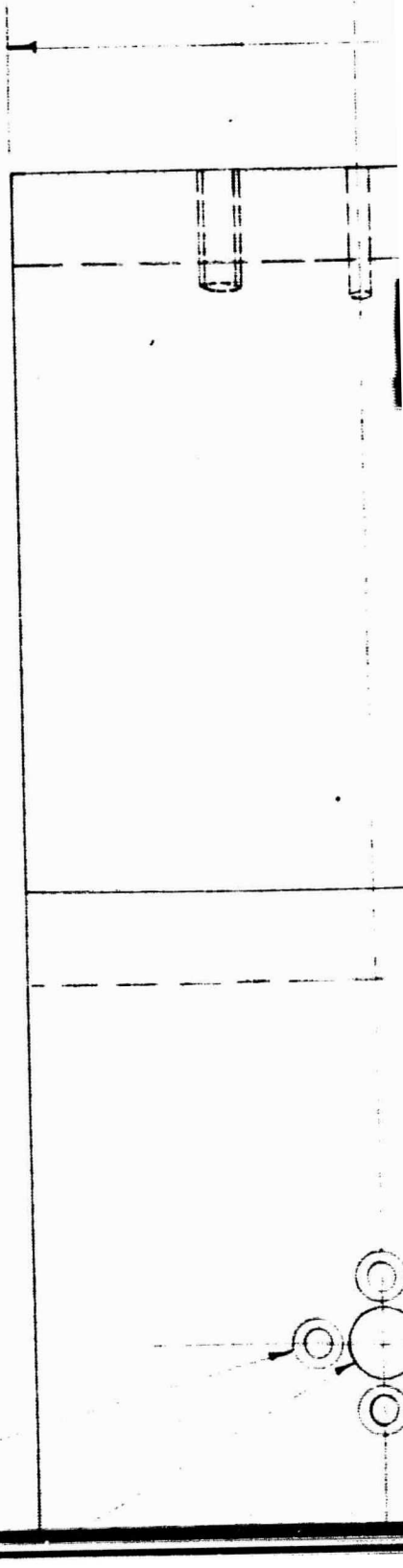
UDE ENGINEERING LABORATORY
NIVERSITY OF MICHIGAN
OF AERO. AND ASTRO. ENGINEERING
BOR MICHIGAN

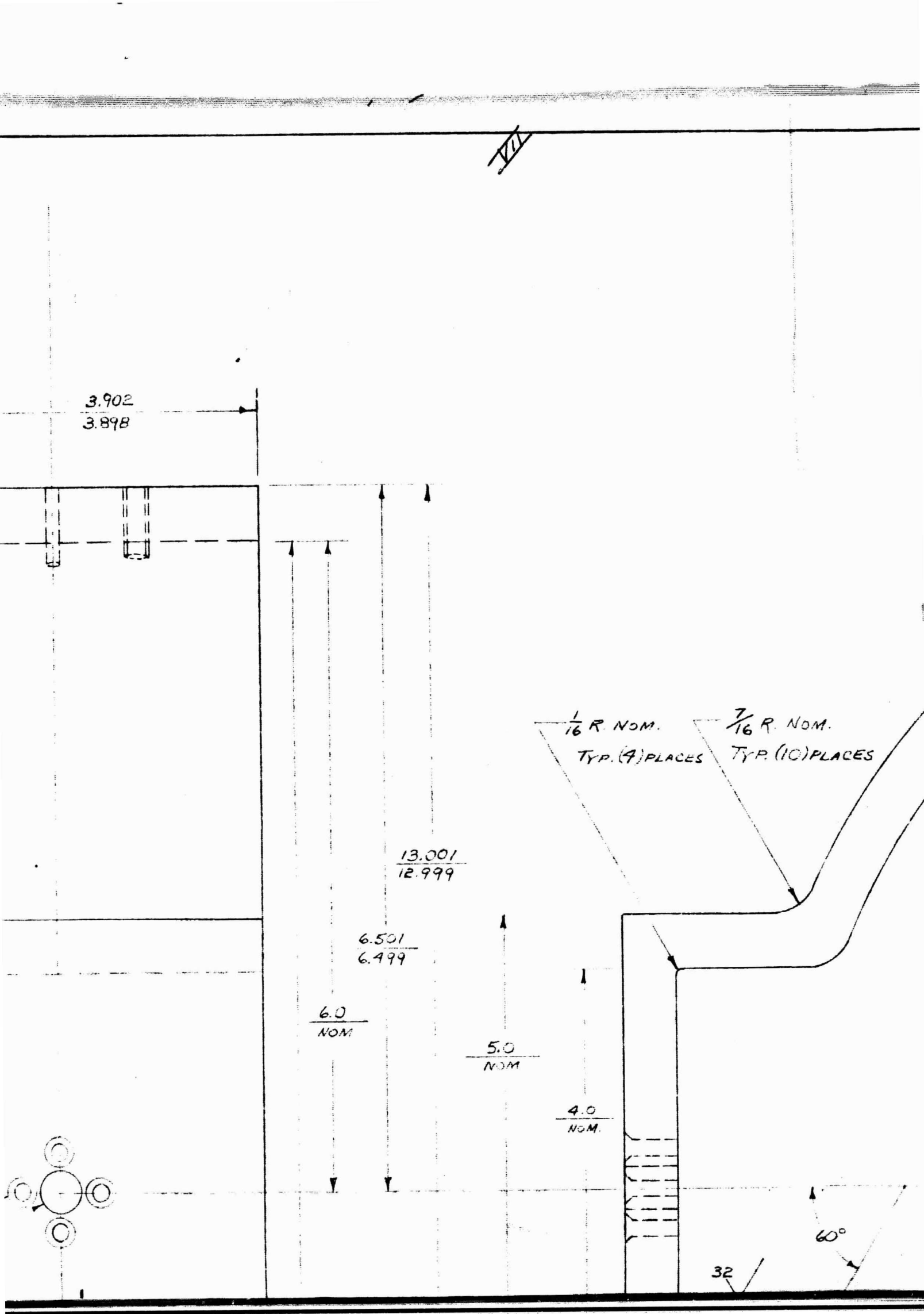
DDLE GIMBAL

H5-52001

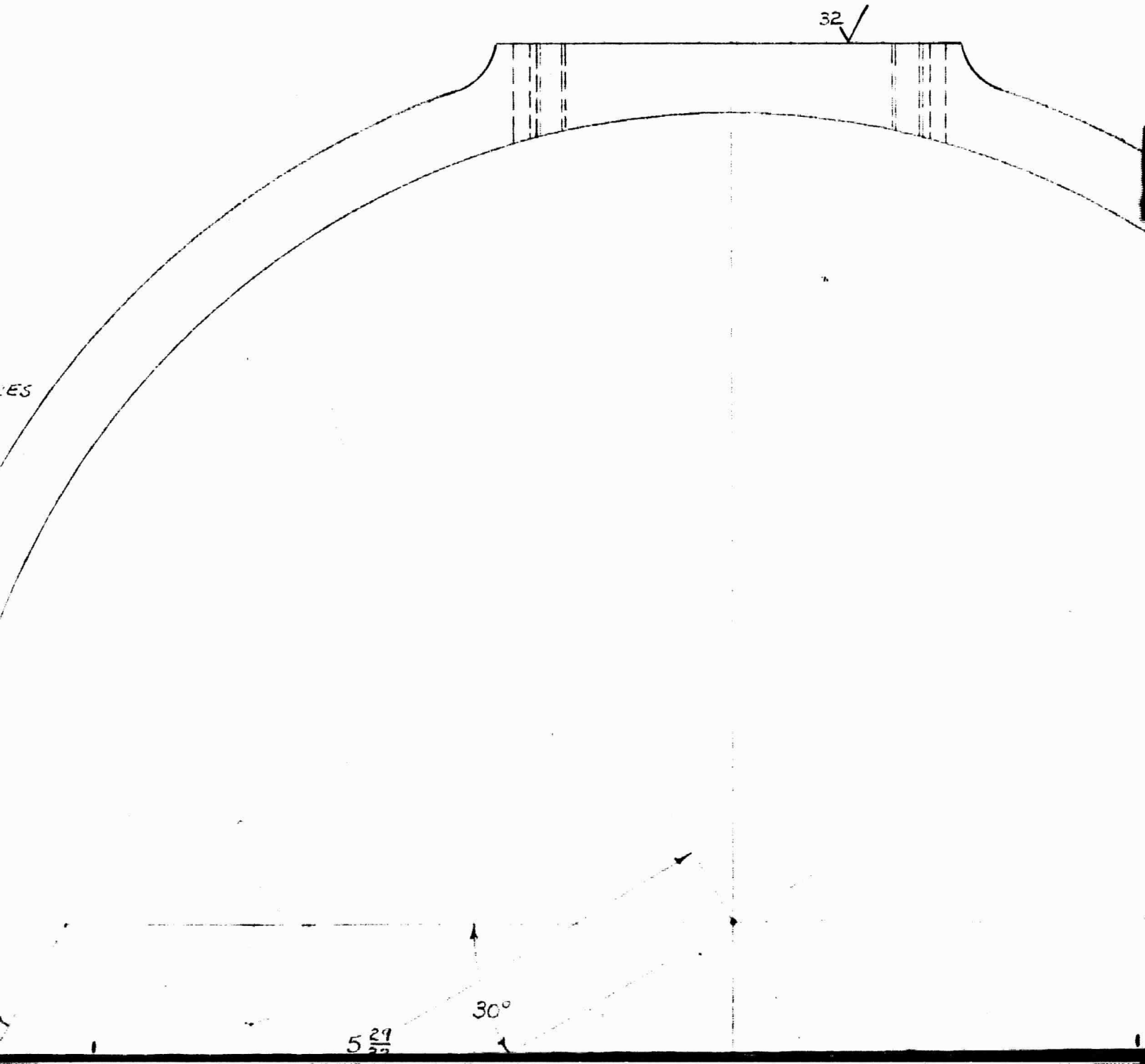
NOTES:

1. BREAK EDGES.
2. ANODIZE.

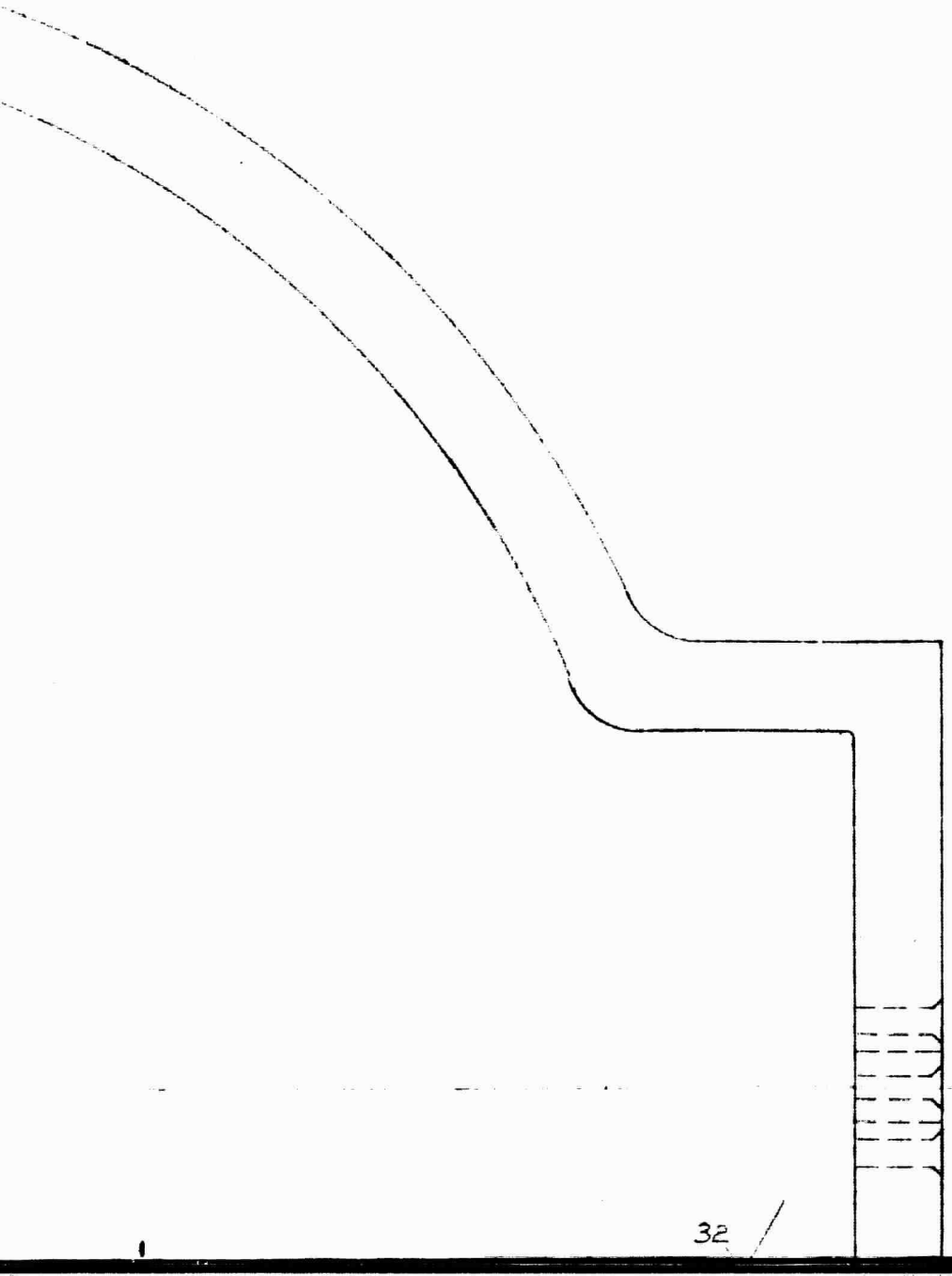


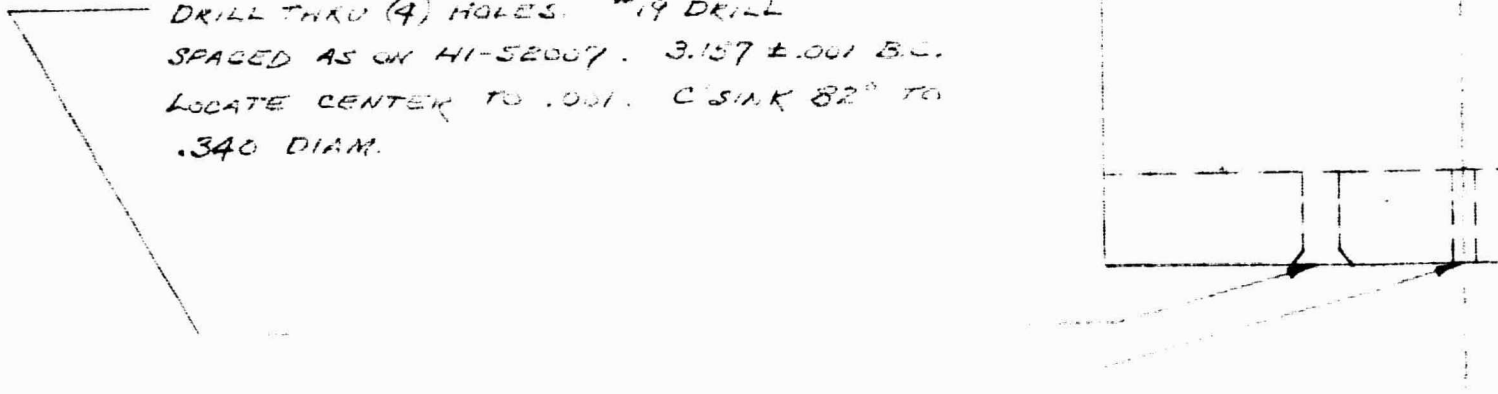

3.902
3.898
13.001
12.999
6.501
6.499
6.0
NOM
5.0
NOM
4.0
NOM
1/16 R. NOM.
TYP. (4) PLACES
7/16 R. NOM.
TYP. (10) PLACES
60°
32

VIII



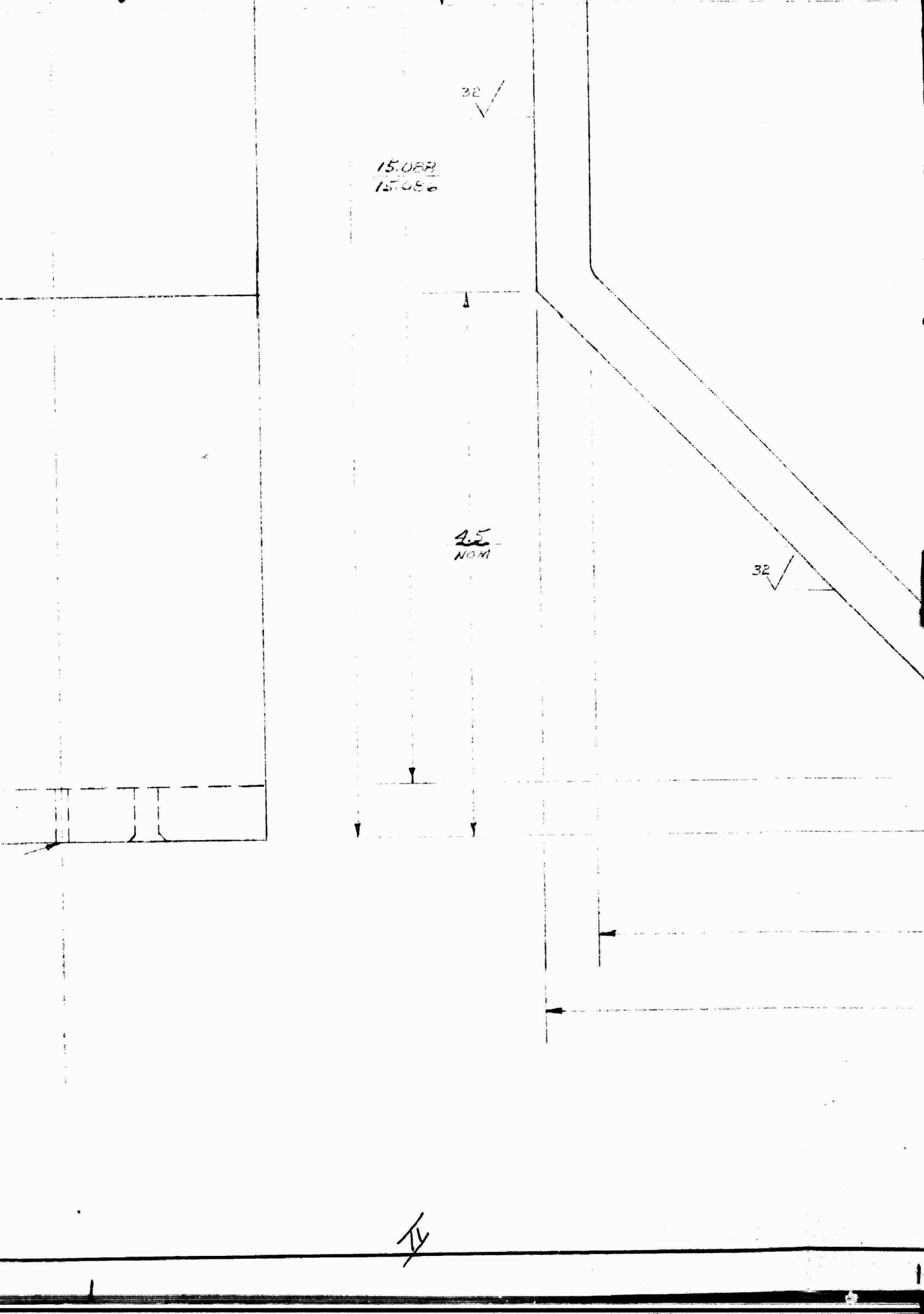
IX

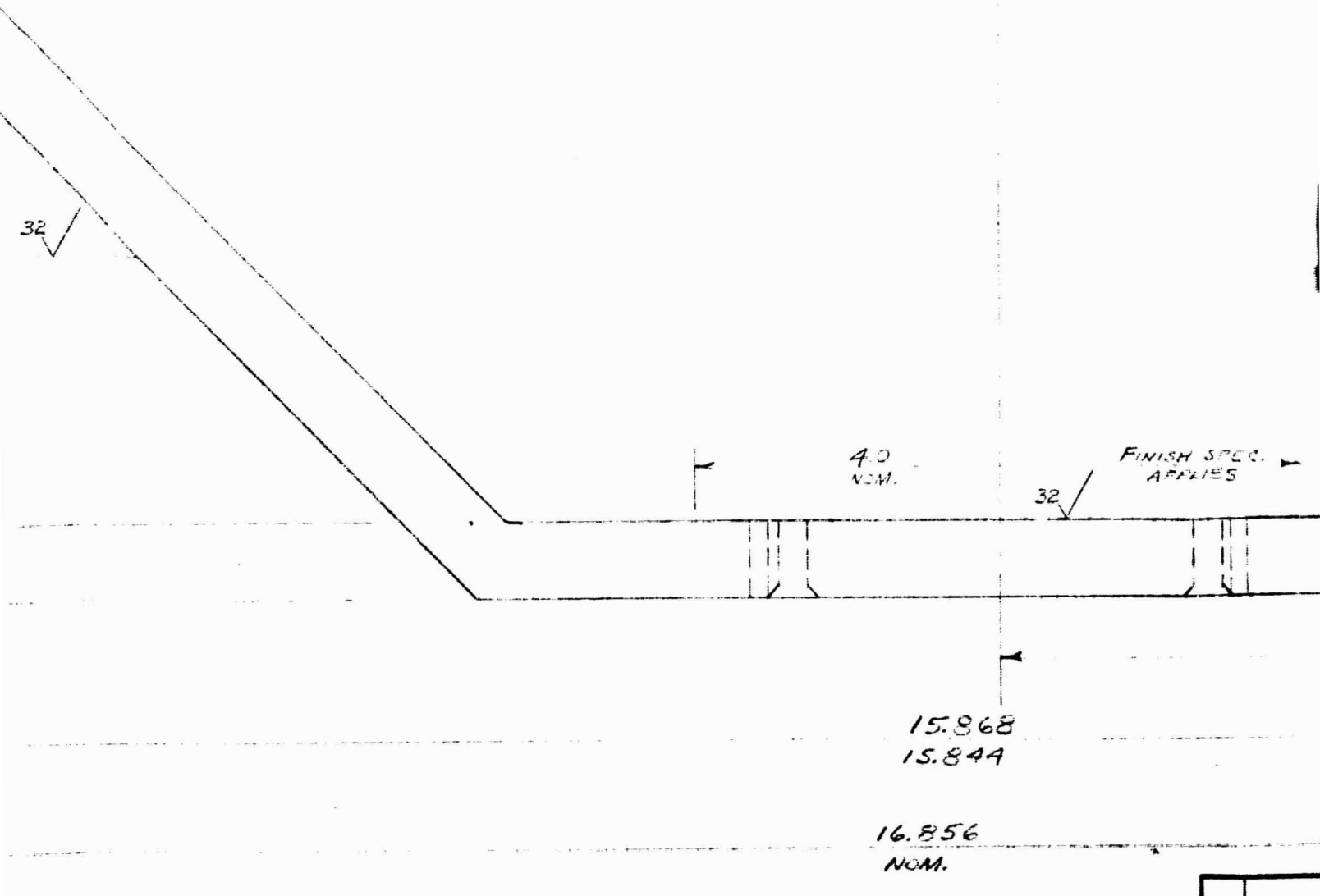




DRILL THRU (4) HOLES. #19 DRILL
SPACED AS ON HI-52007. 3.137 ±.001 B.C.
LOCATE CENTER TO .001. C'SINK 82° TO
.340 DIAM.

(2) HOLES ON 3.1570 ±.0002 B.C.
.1252 - .1256 DIAM. LOCATE CENTER TO .001
CHAMFER 1/16 NOM.


32
15.08R
15.06
4.5
NOM
32



LST.

32 ✓

FINISH SPEC. APPLIES

32 ✓

7.940
7.916

			SCALE	FULL	HIGH ALTITUDE ENGIN UNIVERSITY O DEPARTMENT OF AERO. A ANN ARBOR
			PROJ. NO.	01114	
			DRAWN BY	F3	
			DATE	4-23-68	NAME OUTER
			FOR ASSEMBLY		
			MATERIAL	AZ-31B	DRAWING NO. H5-
LET.	CHANGE	DATE	WEIGHT CAL. ACT.		

1

ITUDE ENGINEERING LABORATORY
UNIVERSITY OF MICHIGAN
OF AERO. AND ASTRO. ENGINEERING
ARBOR MICHIGAN

UTER GIMBAL

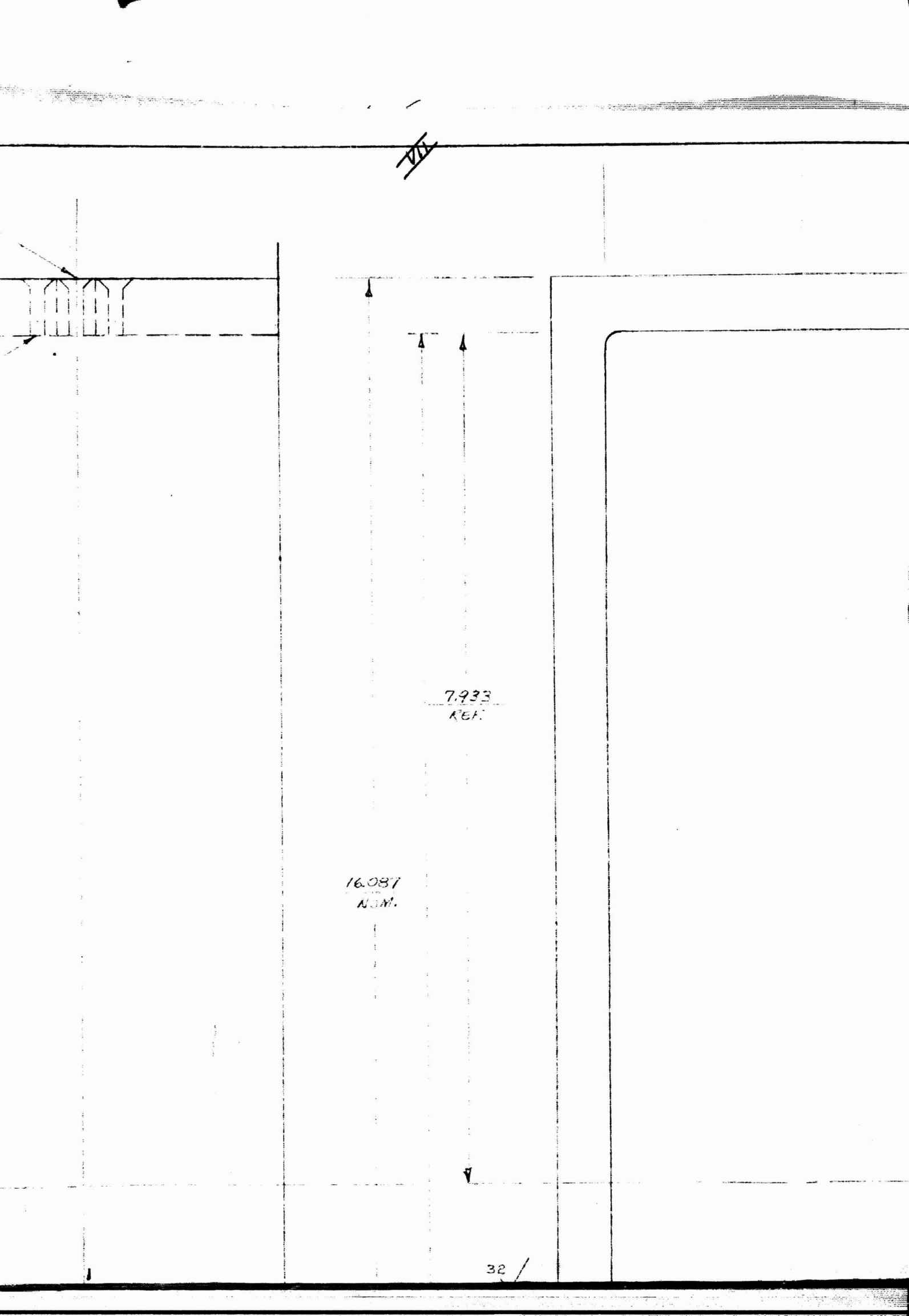
H5-52002

.3752 - .3756 DIAM. HOLE
CHAMFER 1/16 NOM LOCATE CENTER TO .001

DRILL THRU (4) HOLES. #28 DRILL
EQUALLY SPACED ON .750 ± .001 B C
LOCATE CENTER TO .005. 82° C'SINK TO .280
DIAM.

NOTES:

1. BREAK EDGES.
2. ANOD. 2E.


7.933
REF.
16.087
N.M.

VIII